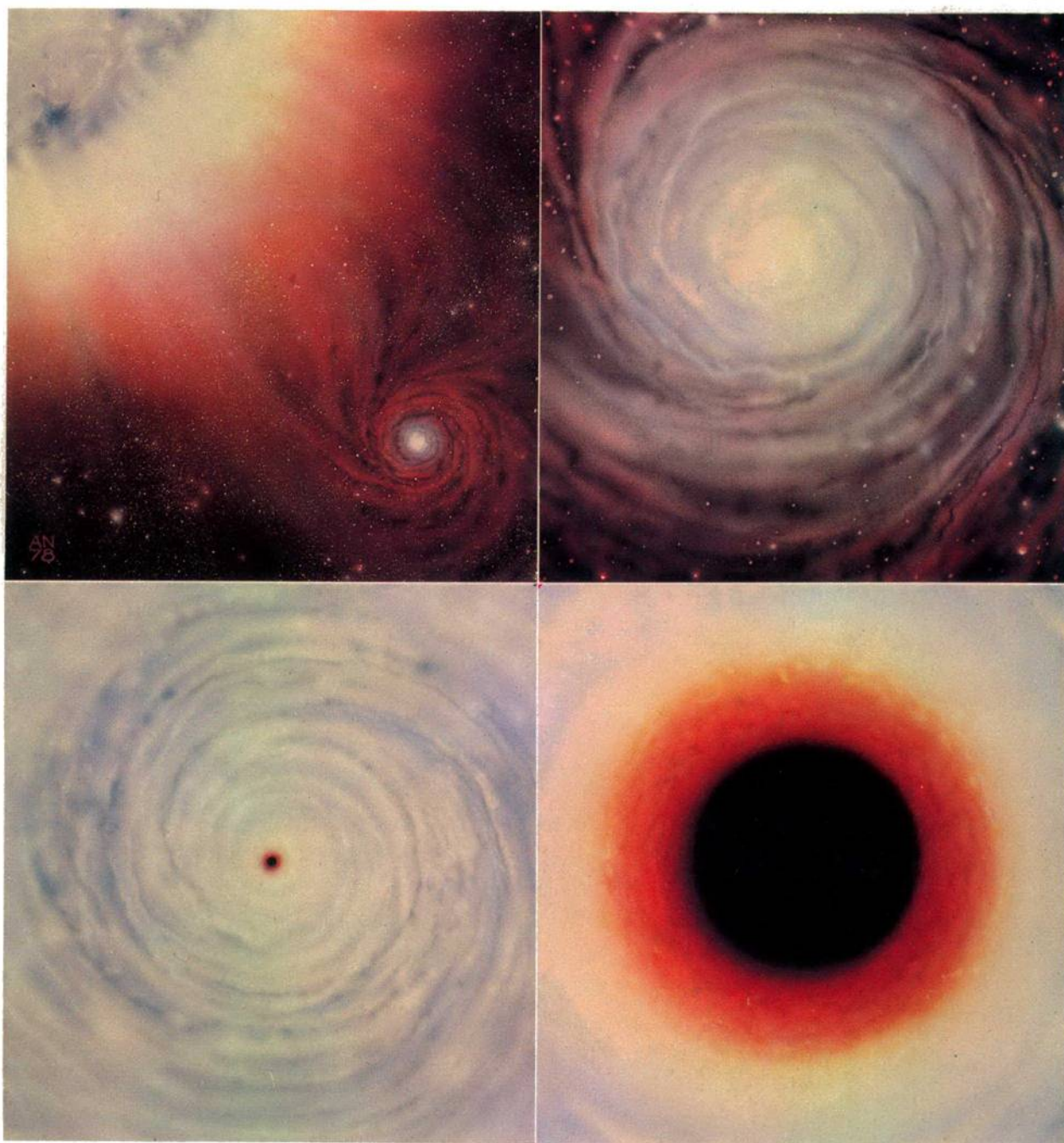


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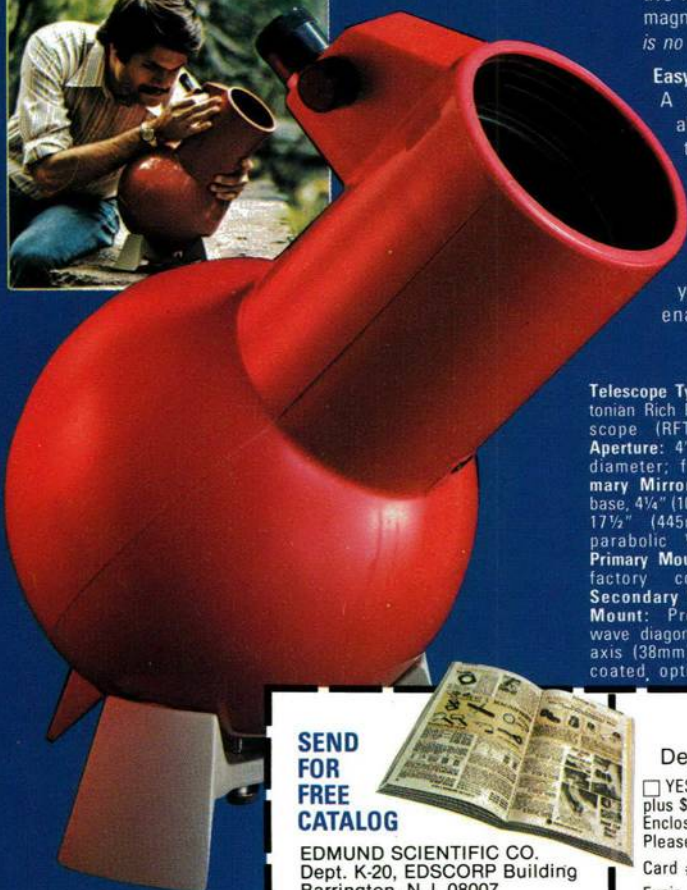
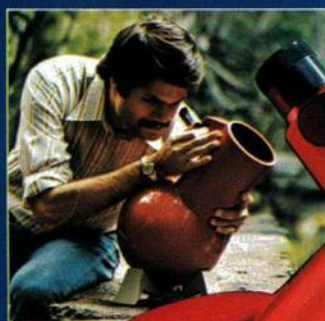
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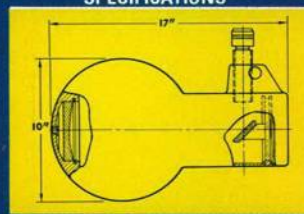
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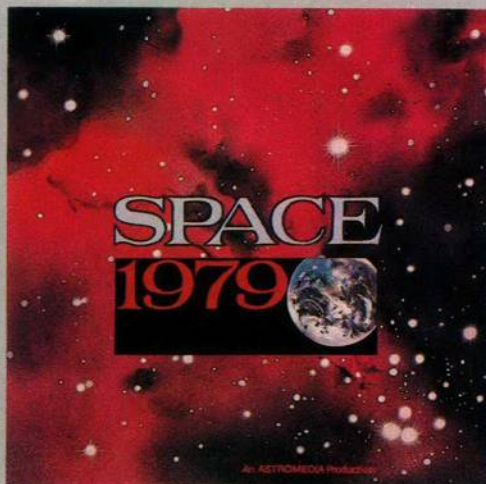
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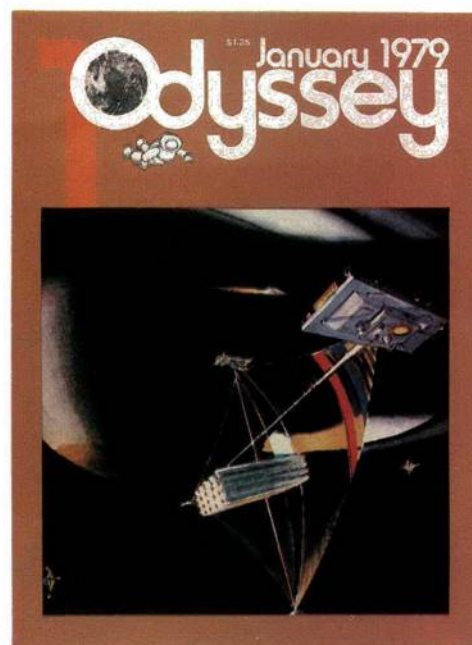
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Robert A. Maas

Robert A. Maas
President
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Vol. 6, No. 10

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Cover

The mysterious black hole in the x-ray binary system Cygnus X-1 is the subject of this month's cover. To show both the black hole and its blue giant companion star, the artist approached the scene in four steps. The first view (upper left) shows both the blue giant and the black hole from perhaps 10 million miles out. Streams of hot gas from the outer layers of the blue giant are captured by the gravitational pull of the black hole and stream into an accretion disk shown in the next panel (upper right). From perhaps 100,000 miles out, the accretion disk shows a ragged, lumpy flow of gas spiraling inward and heating. Still closer, at 1,000 miles out, the next frame (lower left) shows extraordinary heating of a fat ring of gas. It emits copious amounts of visible and ultraviolet light. The final frame shows the black hole itself from a mere 10 mile distance; the gas from the giant streams x-rays as it falls into oblivion. Artwork by Anne Norcia.

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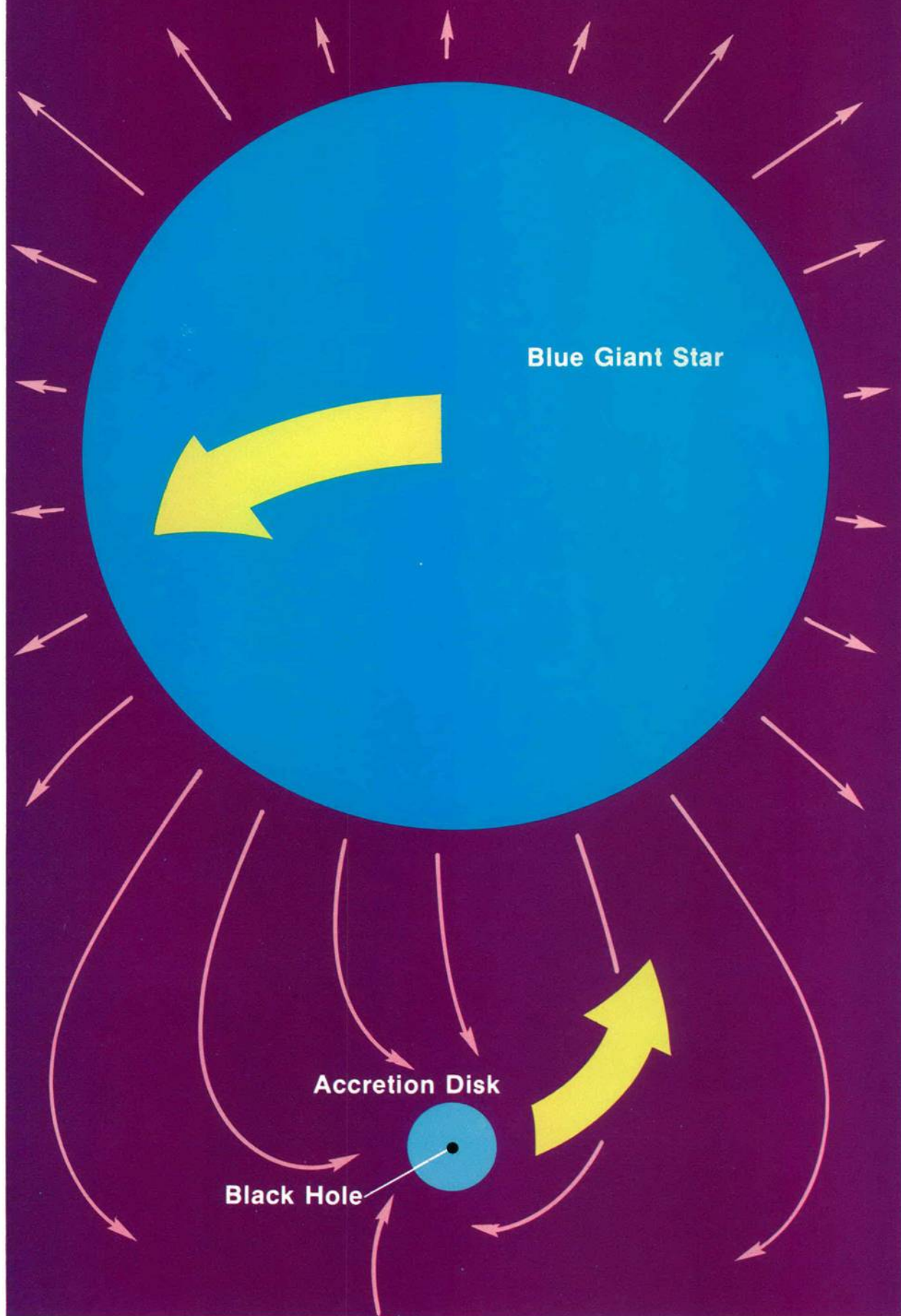
ARE BLACK HOLES REALLY THERE?

by
Gregory A. Shields

In the hearts of massive galaxies may lurk giant black holes, their masses greater than a billion suns. These galaxies emit prodigious quantities of energy — far greater than the output of all the stars in our galaxy. Astronomers now think their fuel could be the stars of the galactic cores — stars unlucky enough to pass too close to continue on by. Here, from the surface of a planet that orbited a star deep in the core of one these galaxies, we see the star it used to orbit disrupted by the tidal pull of the black hole. The star is now exploding. In the distance, high in the eerie sky, is the accretion disk of the black hole and the remnants of other disrupted stars. Streaming from the top and bottom of the disk near the hole is a jet of ultrahigh energy atomic particles — ejected from the accretion disk by powerful electric and magnetic fields. These streams — from far outside the galaxy — will cause astronomers to speculate about the cores of certain peculiar galaxies. Artwork by David Egge.



Scheme for a Binary X-Ray Source



Black holes excite the imagination and stump the minds of nearly everyone who has heard of them. The very idea of space warped about mass until nothing — not even light itself — could ever escape it, and of time and energy distorted, lies beyond human comprehension. Yet “black hole” has almost become a household word. Their popularity — indeed our awareness of their possible existence — stems from a surge of interest in the last decade or so among astrophysicists who explore the theoretical properties of black holes, as well as astronomers who look for black holes in the real universe.

The idea of a black hole was suggested by Pierre Simon LaPlace almost two centuries ago. However, the *modern* concept dates back to 1916, when physicist Karl Schwarzschild discovered an interesting mathematical property of Einstein’s then-new theory of general relativity (about the nature of gravitation). Schwarzschild described a hypothetical region of space with an intense gravitational field pulling toward an invisible center of attraction. He reasoned that an approaching spaceship would be pulled toward this center with a force that grew stronger as the spaceship drew closer. If the spaceship ventured within a certain crucial distance, the force would become so strong that the spaceship could never escape, no matter how powerful its engines. The spaceship would quickly be pulled to the center of attraction, where gravitational forces would crush it out of existence. The crucial distance from the center — the point of no return — is called the *Schwarzschild radius* or, more simply, the *horizon*. The space inside the Schwarzschild radius is called a black hole.

A precise understanding of black holes requires the difficult mathematics of general relativity, which describes gravity in terms of curvature in a four-dimensional geometry combining space and time. Nevertheless, some properties of black holes can be illustrated with the more familiar concepts of Newtonian gravity — especially that of an escape velocity. Living in the space age, we know that if a rocket launched from Earth’s surface reaches a velocity greater than seven kilometers per second — about 25,000 m.p.h. — it will break free of Earth’s gravity and fly out into space. The escape velocity from the surface of a body depends directly on its mass and *inversely* on its radius. If, for some reason, a body contracts and its mass is squeezed into an extremely small radius, the escape velocity can become equal to the speed of light. Then, according to relativity theory, no object can move fast enough to overcome gravity; even light itself is unable to escape. A black hole is born.

Cygnus X-1 seems to consist of a black hole and a blue star in orbit around each other. Some of the hot “wind” of material blowing off the blue star is captured in an accretion disk and spirals into the black hole. If the black hole were shown to scale here, it would be a dot only one-millionth inch across.

Once that point is reached, the body cannot even hold its own against the tremendous force of its own weight, regardless of the material it’s made of. According to general relativity, the body collapses into an infinitesimal volume, and its substance — as we know it — is destroyed. Yet its gravity remains, pulling on distant objects with the same force as it did before it collapsed. Thus the mass of a black hole is defined by its gravitational attraction on an object at some given large distance. The mass of the black hole is the same as that of the original body, and its radius (meaning the radius of the horizon) is proportional to its mass.

For our sun to become a black hole, it would have to collapse to a radius of three kilometers — about two miles — compared with its actual radius of 700,000 kilometers. For Earth, the corresponding value is one centimeter — a bit under 1/2 inch.

Gravity has several important effects on a small object falling into a black hole. An object would be accelerated to nearly the speed of light as it approaches the horizon, and as it falls in it would be torn apart by a tug-of-war between gravitational forces on different parts of itself. Afterward, the black hole would be a little more massive.

Thus far, we’ve discussed the theoretical properties of black holes. But do such things really exist in nature? Today, astronomers think they do. One possibility is that black holes are formed during the death of a giant star — one containing 30 times more matter than our sun. After such a star has exhausted its thermonuclear fuel, it cannot generate enough heat in its center to hold up its own immense weight. It may then contract violently to form a black hole. Smaller stars — such as our sun — do not weigh enough for this to happen.

Observational evidence for such an occurrence in our galaxy is provided by x-rays received from space. The Uhuru satellite, launched into orbit in 1970, contained an x-ray telescope which could accurately measure the intensity and direction of individual x-ray sources in the sky. One of these, called Cygnus X-1 (the first x-ray source discovered in the constellation Cygnus), has properties which lead many astronomers to believe it contains a black hole.

X-rays from Cygnus X-1 are coming from the direction of the bright blue star HD226868, which looks normal for a star with a mass 30 times that of the sun. Since such stars do not emit x-rays by themselves, there must be something else involved — and spectroscopy shows that indeed there is. The wavelengths of lines in the spectrum of the blue star cyclically increase and decrease with a period of 5.6 days. The interpretation is that HD226868 has an invisible companion “star”, and both stars orbit around their center of mass. In this case, the wavelength shift is caused by the Doppler effect. From the orbital period and the velocity deduced

V861 Sco — Another Black Hole Candidate

Researchers using NASA's Copernicus satellite — an orbiting observatory satellite — feel they have found another likely black hole orbiting the variable star V861 in the constellation Scorpius. The new object is about 5,000 light-years from us, and is one of a group of x-ray sources in the direction of the galactic center.

Two of the instruments on Copernicus were used in the observations of V861 Sco: the x-ray telescope and the ultraviolet spectrometer.

V861 is a binary system; one component is a supergiant star and the other is invisible. Since 1970, though, the invisible companion has been thought to be massive enough to be a black hole. V861 is a fairly modest source of x-rays that periodically shuts off — as the x-ray source is eclipsed. The x-rays presumably come from gases spiraling into an accretion disk and into the black hole. The gas emits x-rays as it falls. With the ultraviolet spectrometer, only the supergiant can be detected. Its spectrum shows that this star is blowing off its surface material at a very high rate — enough to supply the gas for the x-ray source that orbits it.

Neutron stars and certain other types of objects can also emit x-rays, but V861 Sco is probably none of these. Researchers have deduced the orbits — and hence the masses — of the components: The x-ray source turns out to have 12 to 14 times as much mass as the sun. Neutron stars cannot much exceed three times the solar mass without collapsing to form a black hole.

The argument in favor of the x-ray source component actually being a black hole will be clinched if short term periodic fluctuations — which the Copernicus x-ray telescope cannot measure — are detected. Other researchers are now scrambling to obtain measurements with instruments on satellites, and at ground based observatories that can detect these one second fluctuations. 

from the Doppler shift, astronomers estimate that the companion has at least nine times the mass of the sun. This companion — presumably — is the source of the x-rays.

There are two reasons to believe that the x-rays come from a tiny object. First, the x-ray intensity fluctuates erratically on a timescale of thousandths of a second. Since an object cannot change its brightness in much less time than light takes to cross its diameter, the x-rays come from a region not more than about 100km (60 miles) across. Second, the spectrum of the x-rays indicates that they are emitted by material at a temperature of

about 100 million degrees Kelvin. Thermodynamic calculations tell us that a source at this temperature need be only 100km across to emit the observed power.

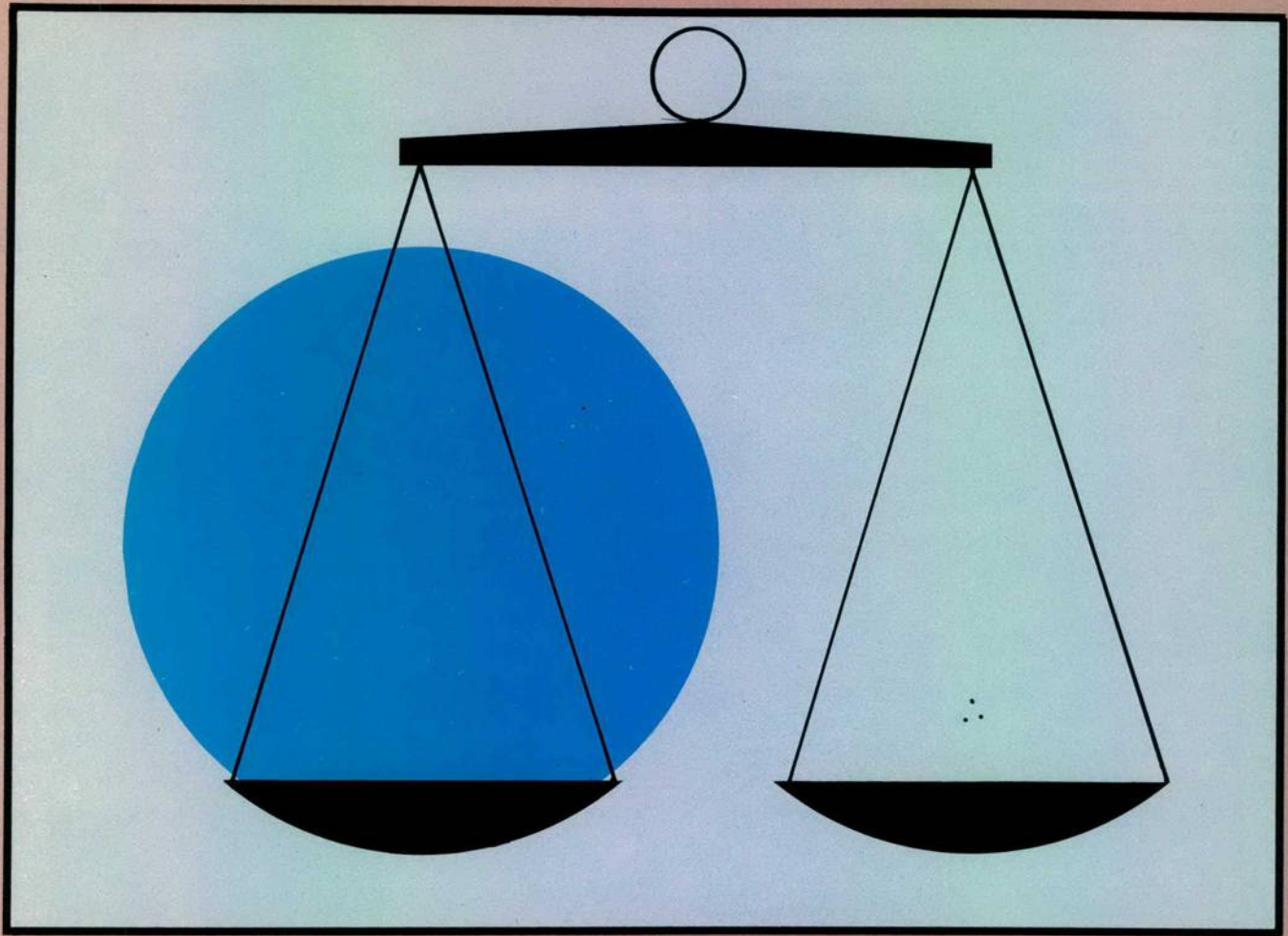
An object this small could be either a neutron star or a black hole. However, the mass of Cygnus X-1 is at least nine solar masses, whereas a neutron star cannot have a mass greater than three solar masses. The only remaining known possibility is a black hole.

Because the existence of a black hole in space is an unprecedented discovery, astronomers and scientists have received the above argument with a proper degree of caution. Several theories have been proposed to explain the same observations without using a black hole. One idea is that Cygnus X-1 belongs to a triple star system. Another is that HD226868 is an abnormal star, whose mass cannot be determined; this would, in turn, invalidate the measurement of the companion's mass. However, most astronomers find the alternatives less persuasive than the idea that Cygnus X-1 is, in fact, a black hole.

How can a black hole be an x-ray source when, according to the very definition of black hole, no radiation can escape from inside the horizon? We can look to the properties of the space near the black hole, outside its horizon for an answer. There we find the black hole's intense gravitational field and, at a distance of about 1/2 the radius of Mercury's orbit, the primary star of the binary HD226868. The surface of HD226868 has a temperature of 30,000 degrees Kelvin, and stars this hot have a tenuous stream of gas constantly "evaporating" into space. Some of this "stellar wind" passes close to the black hole; there, gravity causes the gas to orbit around the hole in the shape of a rotating disk called an accretion disk. Gas closer to the hole orbits more rapidly, and it "rubs" against the more slowly moving gas farther out. This friction causes the gas gradually to spiral closer to the hole, and at the same time heats the gas. (This resembles the death of an Earth satellite, when friction against the atmosphere causes it to spiral closer to Earth and burn up.) As the gas spirals closer and closer to the black hole, its temperature rises. Astrophysicists calculate that at a distance of 10 to 100 times the Schwarzschild radius, the temperature of the gas may reach billions of degrees — and any substance that hot naturally produces x-rays. A given volume of gas spirals through the region of x-ray emission and finally disappears inside the horizon. At the outer edge, fresh gas continually enters the disk. Most of the radiation comes from parts of the disk fairly close to the Schwarzschild radius.

Cygnus X-1 is a few thousand light-years from Earth, only a fraction of the diameter of our galaxy. It is possible that we are also receiving radiation from black holes contained in the most distant known objects, quasars.

Quasars are points of light in the sky whose



Black holes are almost inconceivably small objects. Though three black holes such as one in the Cygnus X-1 system would weigh nearly as much as the blue giant star, they are less than one-millionth the size, and are a million million million times smaller in volume.

spectra imply that they are located at huge distances from the Milky Way. Some quasars are more than 15 billion light-years away, and are receding from us at more than 90 percent the speed of light. In order to be visible at such large distances, quasars must be the most powerful sources of light in the universe. Some radiate a luminosity of 10 trillion suns, making them over 1,000 times brighter than the entire Milky Way galaxy! In addition to optical, infrared and ultraviolet light, some quasars emit radio waves and x-rays.

It's likely that quasars are located in the centers of distant galaxies. They appear to be related to certain nearby galaxies (called Seyfert galaxies) which have tiny, brilliant nuclei that look somewhat like miniquasars. Evidently, in a few galaxies, the energy release in this nucleus is exceptionally powerful, making a full-fledged quasar.

The source of a quasar's tremendous power is a mystery, but several theories have been suggested. One promising theory postulates that a quasar is a galaxy whose nucleus contains an accretion disk around a black hole, similar to — but much larger than — the one in Cygnus X-1. The black hole must

have a mass of 100 million to 10 billion solar masses; if the mass were less, the force of the quasar's own radiation would blow the disk apart. (For comparison, the mass of our entire galaxy is about 70 billion solar masses.) As in the case of Cygnus X-1, evidence that quasars involve black holes comes from estimates of the size of their light producing region. Some quasars change brightness in only a day, implying that the light comes from a region that is about the same size as our solar system. This estimate agrees with the diameter expected for the most luminous regions of an accretion disk around a black hole with a mass of a billion suns.

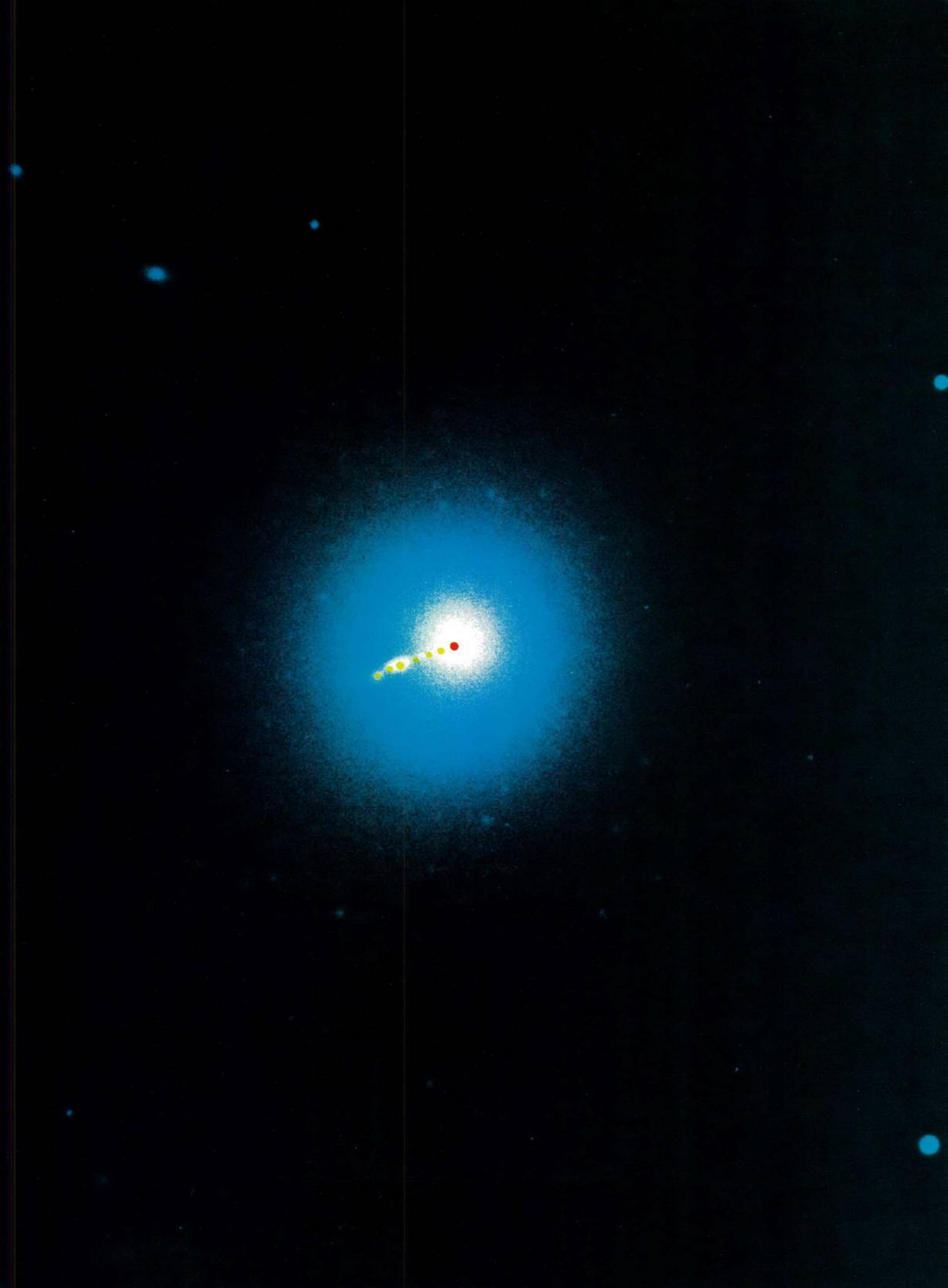
There are several ways gas might reach the outside of such an accretion disk. One source may be gas produced by the normal dying processes of stars crowded into the nucleus of the host galaxy. As the stars become red giants, their outer layers escape into space. It's possible this gas collects in the center of the galaxy and spirals into the hypothetical black hole.

But there are other, more exotic possible sources of fuel for the quasar. All stars in a galaxy move in orbits around the center of the galaxy. Some stars' orbits will carry them near the black hole in the center, where — by raising giant tides — the hole's gravity can rip them apart. This model is called the "black tide". The debris of a tidal disrupted star

Clues to understanding quasars, active galaxies, radio galaxies, and galactic "jets" (see next page) must come from the combined efforts of radio astronomers, x-ray and ultraviolet astronomers, optical astronomers, theoretical astronomers, and physicists all working together to understand what must be going on out there in space. The charged particle jets shown here — based on a theory by Richard Lovelace of Cornell University — are ejected from the accretion disk near the black hole at nearly the speed of light, by very intense electrical fields generated by the spinning magnetized accretion disk. Artwork by Adolf Schaller.







M-87: What's Going On?

In the heart of the Virgo cluster — a cluster of galaxies with over 2,000 members about 65 million light-years away — lies the giant elliptical galaxy M-87. M-87 is perhaps 100 times as massive as our galaxy, and shines with the light of a trillion suns. It is identified with the strong radio source Virgo-A, also known as 3C-274. As a radio galaxy, M-87 emits 500 million times more radio energy than the total energy output of the sun. M-87 is also known as an x-ray source. It is further unusual as it has a large number of globular clusters circling it — nearly 2,000 of them (far more than is normal for an elliptical galaxy).

But M-87 has one outstanding peculiarity: Extending some 20 seconds of arc — about 4,000 light-years at M-87's distance — is a luminous jet. Light from the jet shows a featureless continuum spectrum, and is partially polarized. Observations imply that the jet glows by the synchrotron process — an interaction between high energy electrons and magnetic fields that gives off

radio waves.

Recent studies (see Astro-News, ASTRONOMY, July 1978) show that M-87 is unusual in two more ways: Its core is abnormally bright (implying an excess of stars in the center), and those stars are moving about its core much faster than expected. The result is that astronomers suspect that M-87 contains a very massive object — having perhaps five billion solar masses — at the center of M-87. This object is likely to be a giant black hole! The energy released by stars falling into the black hole via an accretion disk structure (see the painting on pages 6 and 7) would be enough to power M-87's prodigious radio and x-ray output. It could also explain the very peculiar jet structure as material ejected by powerful electric fields from a disk as material whirls into the hole.

Another object with a jet is the well-known quasar 3C-273, the brightest quasar known. Quasars have been giant black hole candidates for some time because there are few other ways to

explain quasars' apparently enormous generation of energy. 3C-273's jet displays a spectrum similar to M-87's. Finally, the galaxy NGC-6251 has an intense radio emitting "torch" some five light-years long at its core! Streaming outward from the torch for 600,000 light-years is a vast trail of gas; around them (and in line with the jet) lie vast clouds of gas extending six million light-years. The central jet — possibly powered by a giant black hole — is carrying thousands of solar masses of material away from the core of NGC-6251 every year.

At present, astronomers are being very conservative, for it's possible the observations can be explained without invoking supermassive black holes. At this point, better observations — at higher resolving powers — are needed to continue the study of M-87 and quasars. This capability will come in the early to mid-1980s, when NASA's Space Telescope goes into orbit.

would remain as a cloud of gas circling around the black hole, possibly forming an accretion disk. Another source of material could come from stars orbiting near the hole that collide. The stars would be moving so fast that a collision could destroy both, again supplying gas to the hole.

In addition to light, quasars often produce strong radio signals. From the radio spectrum, there is little doubt that the radio waves are produced by cosmic rays spiraling through a strong magnetic field in space outside the black hole. The optical light and x-rays may also result from this process. There is an unsolved question: What makes the cosmic rays and magnetic fields? Here again, the accretion disk provides an answer. All interstellar gas, as well as gas in stars, is observed to contain a weak magnetic field. If such gas enters an

accretion disk, the spiraling motion greatly amplifies the magnetic field. Eventually, the field becomes so powerful that it literally explodes out of the disk. Such disk flares may produce cosmic rays, much as flares on the surface of the sun do.

At this point the presence of a giant black hole in the nucleus of a galaxy seems to explain a lot. But where did it come from? A fascinating possibility is tucked away in the black tide model. Imagine that among the hundreds of millions of stars in the nucleus of the host galaxy, some are likely to be massive kinds which die leaving behind 10 solar mass black holes like Cygnus X-1. Occasionally — especially in the crowded regions near the center of a galaxy — another star will pass close enough to such a black hole to be tidally disrupted. If the hole swallows the debris, its mass increases along with its diameter. This makes it likely for additional stars to be disrupted and swallowed. The process continues at an accelerating pace. When the black hole grows to 100 million solar masses, the disk becomes bright enough that the galaxy is called a quasar. Eventually — after some millions or tens of millions

This composite view of the galaxy M-87 shows the outer envelope of globular clusters (the small fuzzy dots), the main body of the elliptical galaxy consisting of billions of normal stars, the mysterious jet, and the tiny unusual core of this object. The colors in this composite do not represent the actual colors of the galaxy. Photographs from Lick Observatory, Hale Observatories, and the JPL Image Processing Lab.

of years — after the hole has eaten most of the densely packed stars in the nucleus of the galaxy, the disk fades. The remaining stars are so far apart that only rarely does one pass near enough to be disrupted by the hole. The quasar is dead, but the giant black hole remains in the center of the galaxy forever.

A variation of this model has been developed at the University of Texas in Austin by J. Craig Wheeler and myself: The stars in galactic nuclei are probably too far apart to fuel a quasar continuously. However, it seems possible that a quasar may be dormant most of the time, with occasional periods of high luminosity. This behavior can be explained by our “black flash” model, in which stellar debris collect in an accretion disk over long periods of time, and then quickly pour into the hole as a result of a change in the properties of the disk. If so, then some nearby, apparently normal galaxies — possibly including the Milky Way itself — may be gathering their strength for a future display of quasar power.

Whatever powers a quasar, there is evidence that many are dead or dormant. The more distant quasars are so far away that their light has been traveling to us for most of the age of the universe (about 15 billion years). When we observe these quasars, we are seeing what the universe was like when it was young. Astronomers find that quasars were much more common then, so that most of the ancient quasars have since turned off.

Recently, astronomers from several countries combined their observations to argue that a giant black hole, possibly a dead quasar, is located at the center of the giant elliptical galaxy M-87. This galaxy is a source of radio waves, and its nucleus contains a faint “jet” of optical light similar to that of quasar 3C-273. However, these radiations from M-87 are much less powerful than from quasars. Two independent observations suggest that the nucleus of M-87 contains a small, dark mass about 10 billion times the mass of the sun. First, spectroscopic observations show that the stars in the nucleus of M-87 are moving unusually rapidly, as though they are being accelerated by the gravity of a great central mass. If this mass were ordinary stars, they would emit more light than is seen — so the mass must be something else. Second, the stars that are present are concentrated toward the nucleus in a way that suggests a strong gravitational attraction toward the center. Regarding the size of the hidden mass, the observations only tell us that it is less than about 1,000 light-years across, whereas a 10 billion solar mass black hole would be only 1/1000 light-year in diameter. The observations, however, are consistent with the presence of a massive black hole. This hidden mass presumably provides the power for the radio emission and optical jet of M-87. A normal elliptical galaxy was observed in the same fashion as M-87, and this galaxy showed no evidence of a central dark mass.



The jet structure of 3C-273 ranks it with an enigmatic — and growing — class of strange objects. Astronomers keep asking themselves, “What mechanism can we think of to eject matter in such a definite pattern?” Hale Observatories photograph.

Further theoretical studies are necessary to determine whether black holes really are capable of explaining what is known about Cygnus X-1 and the quasars. The possible formation of a black hole when a massive star dies also needs theoretical study. And further observational studies are needed. For example, a large telescope in space would be able to observe quasars to larger distances, could measure the radiation from quasars at wavelengths that are blocked by Earth’s atmosphere, and set stronger limits on the size of the central mass in M-87. Judging from the rapid progress made in recent years, it seems possible that only another 5 or 10 years will be needed to answer the question of whether black holes really exist out there. ☛

Dr. Gregory Shields is an assistant professor of astronomy at the University of Texas at Austin. He received his Ph.D from Caltech in 1972, and spent two years at Harvard as a postdoctoral fellow. His research interests include black hole models for x-ray stars and quasars, and the study of ionized nebulae. He has published numerous papers on these topics in professional journals.

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THE NEW ERA IN ULTRAVIOLET ASTRONOMY

by

Fred Espenak

Most of our knowledge about astronomy comes to us through indirect observations, sophisticated inferences and a lot of high powered guesswork. Though no human has ever visited a quasar or seen an interstellar molecule, we know a surprisingly large amount about such exotic and elusive entities. Everything mankind knows about these objects comes to us in the form of the electromagnetic radiation which they radiate — absorb or reflect. In addition to visible light, astronomers now study the entire electromagnetic spectrum — gamma rays, x-rays, ultraviolet, infrared, microwave and radio radiation. Today these are all part of the rich spectrum of hieroglyphics which astronomers must explore in order to decipher the secrets of the universe.

Each energy region in the electromagnetic spectrum allows us to see in a very unique way. Unfortunately, many wavelengths are permanently inaccessible to astronomers using Earthbound telescopes, due to the natural protective envelope which surrounds our planet. Earth's atmosphere shields us from most of the biologically harmful radiations, allowing only visible light and varying amounts of ultraviolet, infrared and radio to reach the ground. Occasionally, a very intense burst of energy in some of the other wavelengths reaches us after being drastically diluted and modified by our atmosphere. However, such events are rare and

give a very incomplete picture of the universe in these wavelengths.

Man's newest and most promising tool for studying ultraviolet radiation from stars, galaxies and nebulae is a satellite named the International Ultraviolet Explorer (IUE), which was launched from Cape Canaveral on Jan. 26, 1978. The IUE follows an elliptical orbit of 25,000 kilometers by 46,000 kilometers. The orbit is geosynchronous, which means that it takes 24 hours for IUE to complete one revolution around Earth. Because the spacecraft remains over one part of Earth, astronomers can use the IUE in much the same way they would a ground based observatory.

In order to reserve telescope time for IUE, astronomers must submit an observing proposal 6 to 12 months in advance. Each proposal must describe the objects the astronomer wishes to observe, and state why such observations are important. Since a limited amount of telescope time is available, only the best proposals will be granted time. Thus, the competition is rather intense, though most ground based observatories operate in much the same way.

To help the guest observer and astronomer, IUE has a permanent staff of experts who supervise the daily science operations. They also conduct the necessary image processing and schedule time for future observers. In addition, they take care of spacecraft maintenance and calibration. Aside from these interruptions, IUE's geosynchronous orbit allows two ground stations — on either side of the Atlantic — to conduct astronomical observations 24 hours a day! During its expected three to five year lifetime, the orbiting observatory may produce over 15,000 ultraviolet spectrograms!

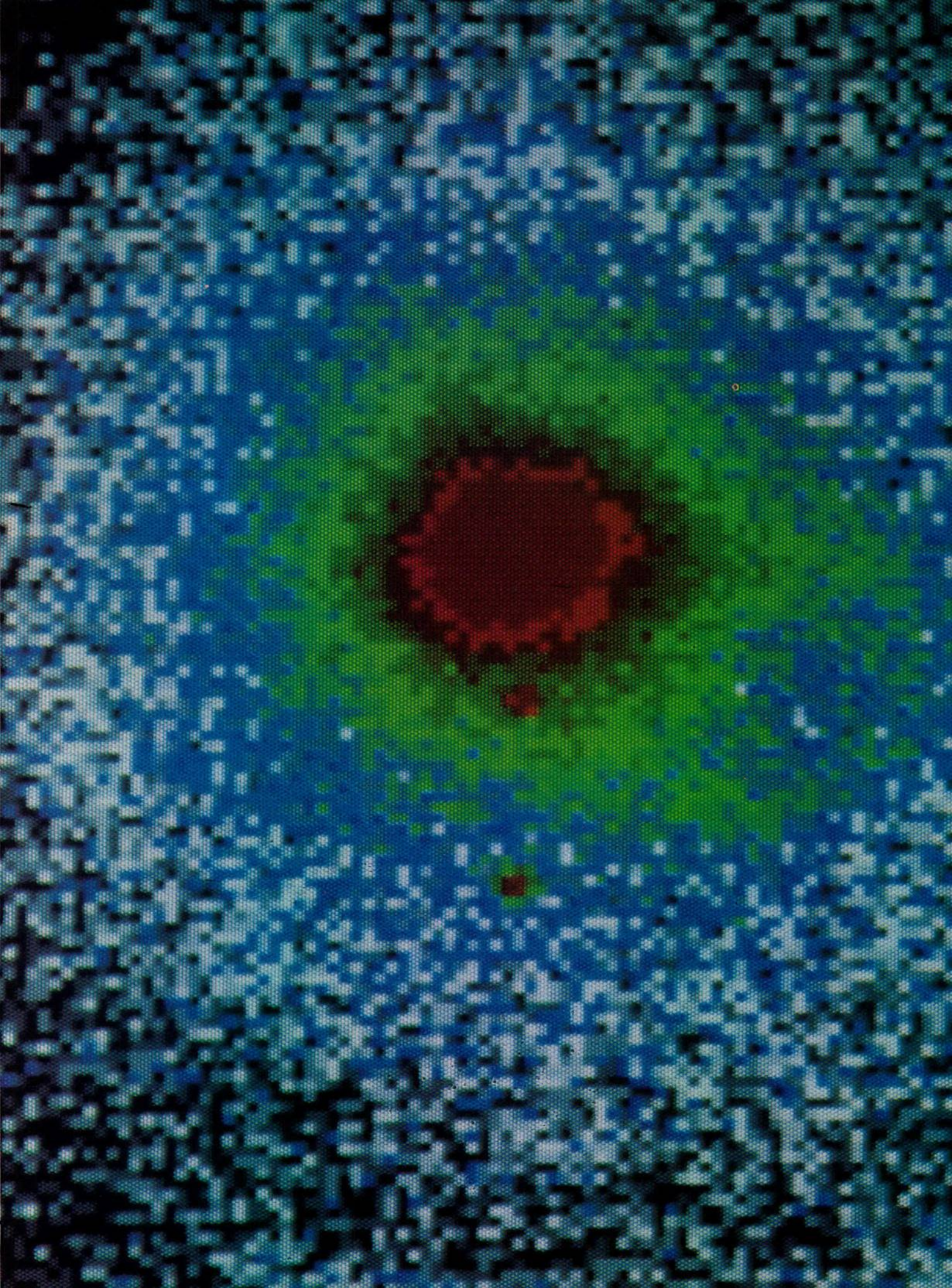
What Will IUE See?

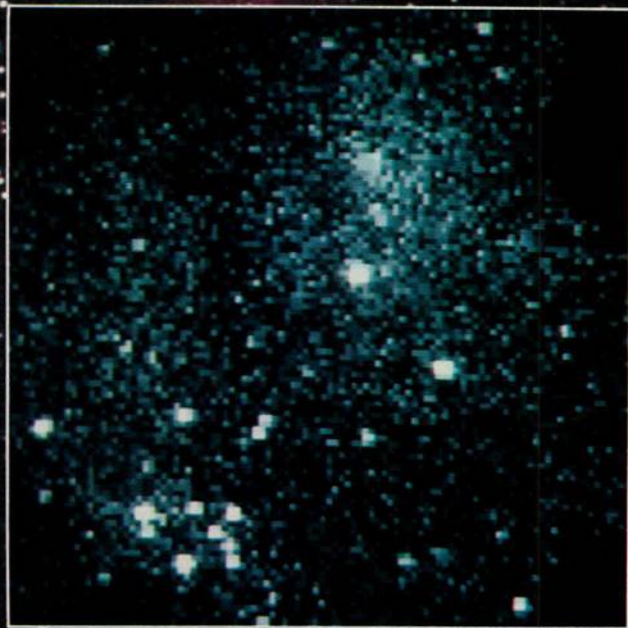
IUE will explore many types of celestial objects — most of them chosen because they pose some kind of mystery to astronomers. Among them are quasars, which appear to be tiny — only a few tens of light-years across — but so brilliant they outshine the biggest and brightest galaxies! How

Who Runs IUE?

IUE is truly international: a joint venture between NASA, the European Space Agency (ESA), and Great Britain's Science Research Council (SRC). Each agency has a financial — as well as scientific — commitment to the project. The SRC and University College (London) built the four spectrograph cameras, while ESA provided a ground station in Spain and built the solar arrays which power the spacecraft. NASA constructed and launched IUE in addition to setting up a ground station at Goddard Space Flight Center in Greenbelt, Md. Almost 200 astronomers representing 17 countries have already been selected to conduct observations during the first year of operation.

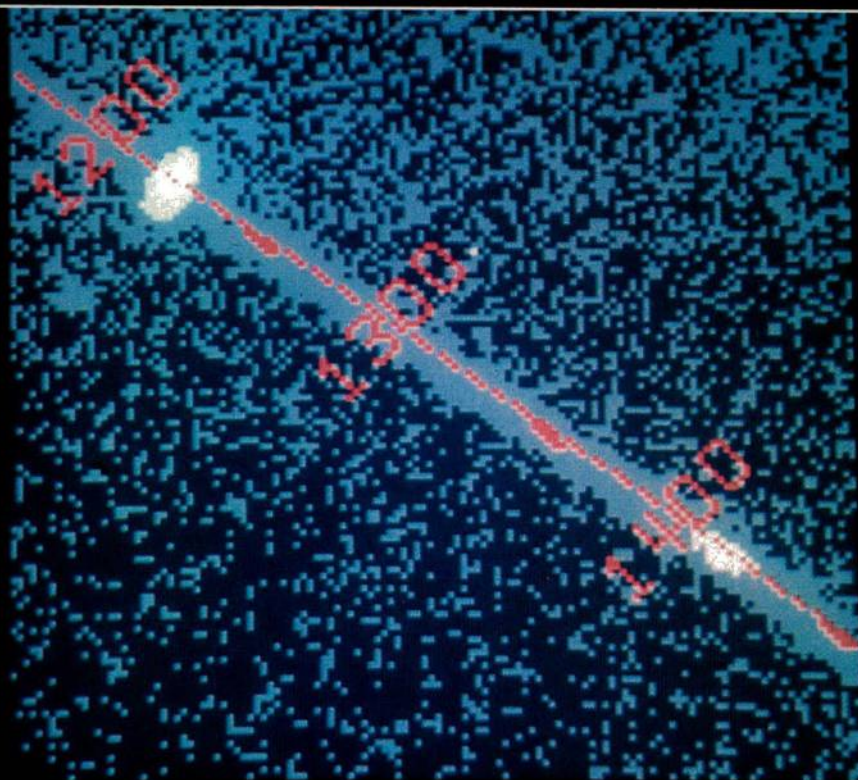
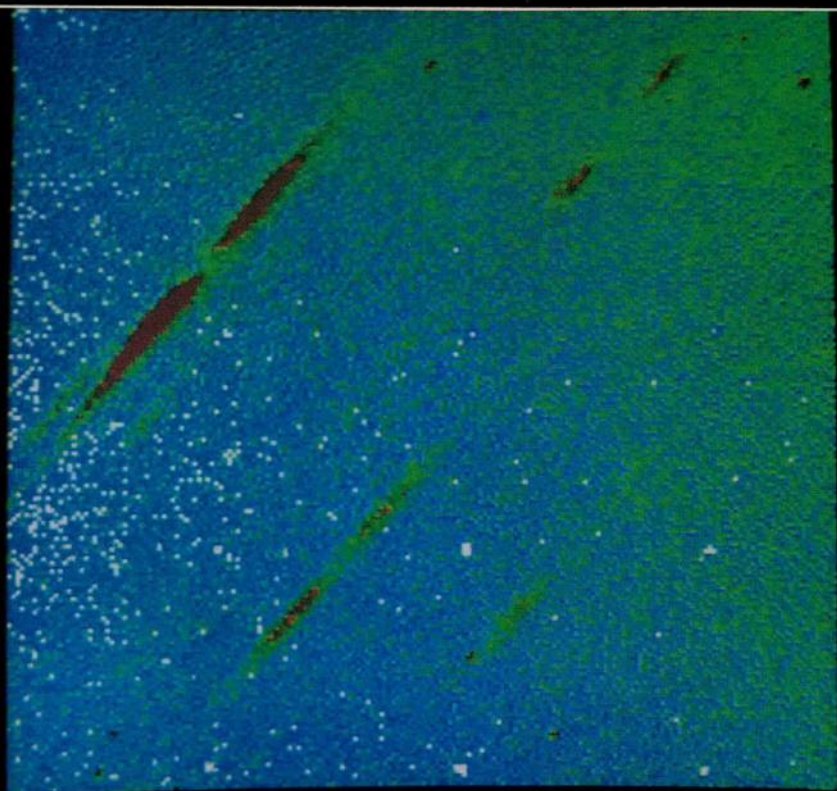
Vividly displayed in false color video imagery, Jupiter (the large bright red ball) and its satellites Io and Ganymede are seen with IUE's Fine Error Sensor camera. This picture was made on Feb. 16, 1978, shortly after the orbiting observatory went into operation. The picture is built up from individual image elements called "pixels", which can be displayed either as brightness values or as colors. Here a color display has been chosen. Photograph courtesy of Fred Espenak.





IUE will study many different types of stars, including young newly formed ones such as those in the heart of the Lagoon nebula. The cluster — containing a number of very hot O and B stars — is still embedded in the nebula in which it formed. The image above shows a small area (16 minutes of arc on a side) of the Lagoon made with IUE's Fine Error Sensor camera. The background image of the Lagoon nebula was taken with the 48 inch United Kingdom Schmidt camera, copyright © 1978 U.K. Schmidt Telescope Unit. IUE photograph courtesy of Fred Espenak.





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quasars generate such incredible amounts of energy is a question of fundamental importance to modern astronomy. A number of the brighter quasars are within the range of IUE. Their ultraviolet spectra may help explain their mysterious nature.

Another type of oddball object — Seyfert galaxies — has bright, starlike nuclei and faint spiral arms. Like quasars, Seyferts seem to be radiating more energy than current theories predict. They are known as strong x-ray and radio sources, with odd spectra containing broad, bright emission lines. Astronomers think Seyferts are filled with very hot gas, but they need to know more.

Other types of peculiar galaxies include those undergoing catastrophic explosions, such as M-82 (in Ursa Major), and radio galaxies like Cygnus A. Astronomers believe there must be some grand underlying relationship between all these objects. Perhaps there is some evolutionary sequence which runs from the oldest quasars through Seyferts and peculiar galaxies, ending with normal galaxies. However, such a grand theory would also have to explain how spiral, barred spiral and elliptical galaxies are related to each other.

In our own galaxy, IUE will participate in the search for such bizarre objects as black holes, neutron stars and white dwarfs. Since these objects are likely to be x-ray emitters, the x-ray stars in Hercules (Hercules X-1) and Cygnus (Cygnus X-1) have already been observed by IUE. These objects are binary systems, each containing a bright primary star and an unseen companion which exerts a gravitational force great enough to tear hot gas free from the primary. As this material spirals down into the unseen companion, friction raises its temperature and x-rays are produced. Observations of Hercules X-1 and Cygnus X-1 will help determine whether the unseen companions are a neutron star and a black hole respectively.

Hot stars will also form an important group of IUE targets. They fall into two basic categories: very young stars and very old stars. The very young hot stars (spectral types O and B) have temperatures up to 50,000 degrees Kelvin! Although they are the brightest objects in our galaxy, these stars pay a heavy price for such prominence: They have short lifetimes. In less than 100 million years, they burn up nearly all their nuclear fuel. This may seem like a long time, but on

Top: A high dispersion spectrum of the binary star Capella shows many spectral emission lines arising from the chromospheres of the two stars. The two stars making up Capella are G stars like the sun, but both are larger, more massive and brighter. The prominent line in the upper right corner is Lyman-alpha of hydrogen; the center of this line has been absorbed by gas in the interstellar medium between us and Capella. **Bottom:** The spectrum of quasar 3C-273 also shows the Lyman-alpha line — in fact it shows it twice! The line in the upper corner comes from the geocorona of Earth, while the line in the lower right comes from the quasar itself. The difference in wavelength between the two lines is a direct measure of the large redshift. Photographs courtesy of Fred Espenak.

How IUE Works

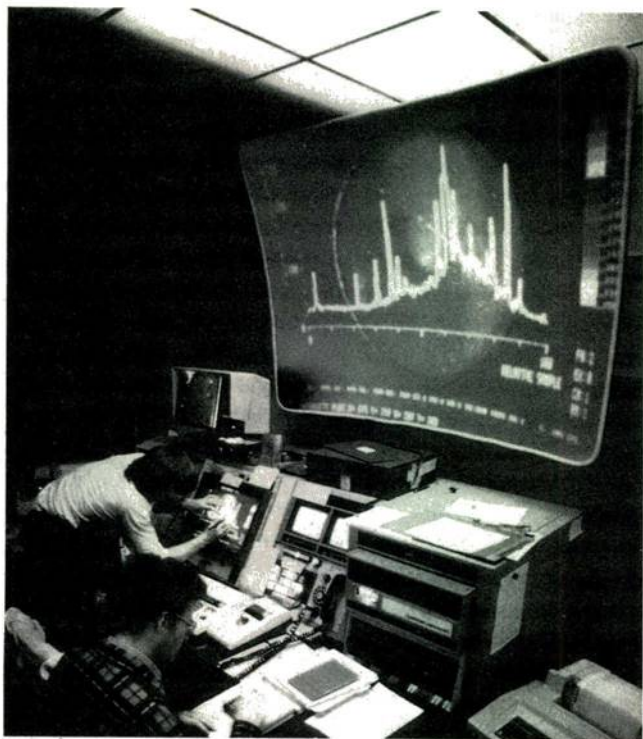
IUE carries a 17.7 inch (45cm) Cassegrain telescope equipped with two spectrographs for studying short (1,150 to 2,000 Ångströms) and long (1,900 to 3,200 Ångströms) wavelengths in the ultraviolet. Four television cameras transmit the spectrograms back to Earth where they are computer reconstructed and color coded to reveal the relative intensities of different spectral lines. Minutes after the exposure is completed, the spectrogram is displayed on a color television monitor where astronomers can study it and decide whether another exposure is required, or to begin observations of another object. Two other cameras onboard function as finder telescopes for identifying star fields, and as automatic star trackers which keep the telescope trained on a star during exposures as long as five or six hours. These Fine Error Sensors (FES) each have a field of view of only 16 minutes of arc, or about 1/2 the diameter of the full moon. This causes a serious problem if the spacecraft loses its orientation in moving from one target to another: The FES would need to take over 200,000 images to map the entire sky!

The 1,500 pound (671kg) satellite is 4.3 meters long and appears to be an octagonal structure with rocket engine and the telescope tube extending from opposite ends. Two large arrays of solar cells extend from either side of IUE like wings and supply the spacecraft with all the necessary electrical power. To control the pointing of the telescope, a set of onboard gyroscopes are commanded from the ground.

The Experiment Display System (EDS) is a sophisticated computer console which is used to coordinate IUE science operations and to process the raw images into high quality spectrograms. The telescope is actively controlled with the EDS by way of a ground computer which checks each command to ensure that it doesn't endanger the health of the spacecraft. The status of the spectrograph cameras, FES, telescope temperature and other spacecraft systems are all monitored from this console. A color television monitor contained in the EDS displays newly acquired spectra or finder field images, and a built-in minicomputer allows astronomers to make a quick analysis of each image.

Several earlier satellites have made important observations in the ultraviolet (NASA's OAO-2 and Copernicus, and ESA's TD-1), but none has been capable of observing such faint interesting objects in so much detail.

In addition, IUE's real-time operation allows astronomers to examine their data immediately and make new observations based on these data.



Astronomer Ralph Bohlin takes a close look at a newly acquired spectrum. A blowup of the spectrum is seen on the large screen overhead. The experiment display system can be used to make intensity plots of the data for "quick look" analysis. Photograph courtesy of Fred Espenak.

the timescale of the universe, it's actually short. Hot young stars are both larger and more massive than the sun; they comprise the most likely candidates for eventually exploding as cataclysmic supernovae. These stars are bright in visible light, but are even brighter in the ultraviolet. In many cases, O stars are still embedded in the nebulae in which they were formed. The Lagoon nebula (M-8) in Sagittarius and M-42 in Orion contain many of these energetic hot stars.

The other class of hot stars IUE will target are highly evolved stars in the last stages of life. The stars in planetary nebulae belong to this category. They seem to be the naked cores of red giants which have blown their extensive atmospheric envelopes off into space. The Ring nebula (M-57) and the Dumbbell (M-27) are classic examples of this group. Their central stars may exceed 100,000 degrees Kelvin at the surface! However, because they are so small, these stars are faint.

At ultraviolet wavelengths, the atmospheres of cool stars like our sun can be examined in detail. Above the visible surface — or photosphere — of these stars lies a thin transition region, the chromosphere. The photosphere acts like a boiling cauldron, transferring tremendous amounts of mechanical energy into the chromosphere, where it is converted into heat energy. In the chromosphere, temperatures climb from 6,000 to 100,000 degrees Kelvin. Beyond the chromosphere lies the corona — the outer boundary of a star — where temperatures soar to several million degrees Kelvin! Studies of

such stellar atmospheres are vital to understanding our own sun and the influence of its atmosphere on Earth.

IUE will turn toward the red giants and supergiants like Antares, Betelgeuse and Mira, to learn about their large, cool atmospheres. These stars appear to be throwing mass off into space at incredibly high rates — several millionths solar mass per year. While not as spectacular as a supernova explosion, such a mass loss must have a very significant effect on the evolution of red giants — but that effect is not understood. Many other stars are undergoing some less extreme form of mass loss — including our own sun, which sheds subatomic particles via the solar wind.

Between the stars lie gas and dust — the interstellar medium. It is by no means uniform; in fact, it's rather patchy and clumpy. It appears to be concentrated in the plane of our galaxy and is densest in the direction of the center of the Milky Way. Astronomers can detect interstellar gas by observing the effects it has on starlight passing through it: The atoms absorb and scatter select wavelengths of light — so that the spectrum of a star reaches us minus these wavelengths. The ultraviolet part of the spectrum is particularly good for detecting these interstellar atoms. Since they are the raw material of stellar formation, a thorough understanding of the interstellar medium is necessary for a complete picture of the evolution of stars.

The planets in our own solar system constitute an important group of targets. Although none of them radiate ultraviolet light, the gases in their atmospheres absorb light. IUE will point at Jupiter's Great Red Spot, the polar icecaps of Mars, the rings of Saturn, and many of the moons in the solar system during the coming years.

In spite of the many tantalizing questions which IUE may help to answer directly, the mission is also a prelude to the 10 ton Space Telescope. This very important space observatory will be launched aboard the Space Shuttle in 1983. Its giant 94 inch (2.4 meter) mirror will have a resolution surpassing every telescope on Earth, and is expected to observe objects 100 times fainter than the 200 inch Hale reflector on Mount Palomar. Astronomers are understandably very anxious to use every bit of its enormous potential as effectively as possible — and IUE is an excellent "training mission" for the Space Telescope. Indeed, it's certain that many of the observing techniques perfected by IUE will be used by the Space Telescope. As such, IUE may be considered the key to Earth's ultimate telescope! 🐾

Fred Espenak works for Computer Sciences Corp. as a computer analyst for Goddard Space Flight Center in Greenbelt, Md. He is a telescope operator for IUE — he sits at the computer console and provides real-time control for the scientific aspects of the satellite's operation. Espenak has a master's degree in astrophysics from the University of Toledo.

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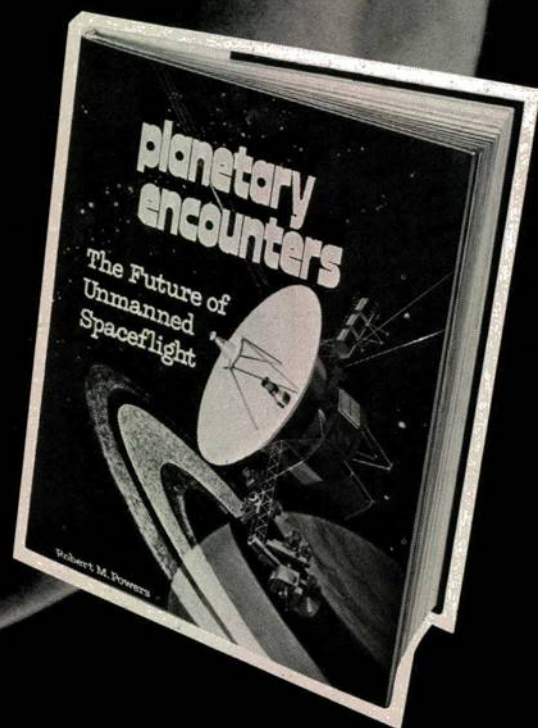
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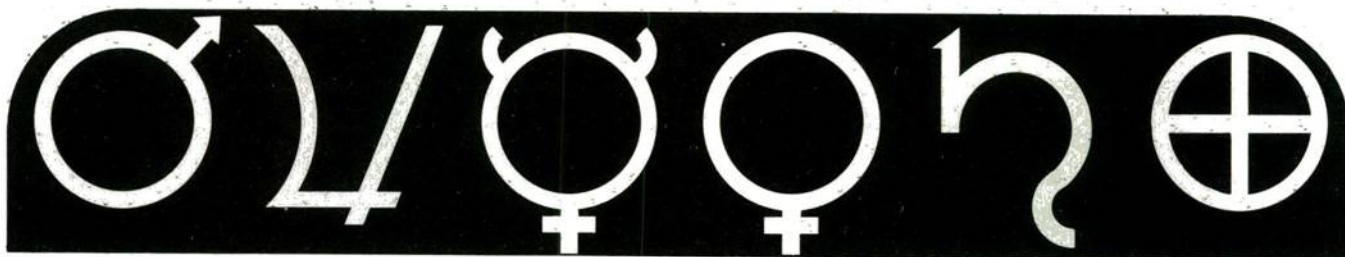
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by

Robert Burnham

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The four major satellites of Jupiter orbit the planet in periods ranging less than 2 days to 17 days. You'll see them change position from night to night. This table shows the approximate position of the moons each night. The column at the far left shows the date; the second column gives the names of the moons (Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4). The third column shows the satellites' positions as they appear through an inverting telescope; south is at the top.

This month is a transition wherein the summer constellations slip away in the early evening and those of winter begin their slow climb up over the eastern horizon. At midnight, Orion has made his appearance, heralded by the Pleiades and Hyades star clusters. By the time dawn is coloring the sky, Sirius and Procyon, the dog stars, are well up in the east and even a bit of the spring sky (Leo) is crawling into view.

October nights are getting cool, and you may notice the sun is setting earlier and earlier. But the chilliness isn't severe enough to deter most observers. Those who do go out, especially in the early morning, will be pleased at the sights. Jupiter and Saturn rule the morning sky, and Mars and Venus the evening — but these last two planets won't be as glorious as the first two. Speaking of planets, there's also a rare event involving Uranus to test your skill this month!

Mercury

Mercury is very hard to catch this month since it went through superior conjunction on the last day of September. Now moving out to the east of the sun, it will still be too close to the sun all month to be seen with the naked eye.

Venus

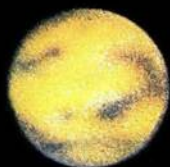
Venus reaches its greatest brightness for this apparition Oct. 3, when it will be at -4.3 magnitude. This planet is the brightest object in the sky — apart from the sun or moon — though its low elevation will keep it from being as spectacular as it sometimes can be. At times Venus has been bright



Taken in Alaska and the Yukon Territories in late April, these beautiful aurora pictures convey the magnificence of high latitude auroral displays. Because summer sunset is so late, most of these pictures show some twilight remaining; in addition, clouds passing overhead are still illuminated. Photographs by R. Beachler and J. Manaccl.



Planet Finder



(A) Mercury

Oct. 1
R.A. 12h30m
Dec. -1°53'
Mag. -1.2

(B) Mercury

Oct. 15
R.A. 13h56m
Dec. -12°05'
Mag. -0.6



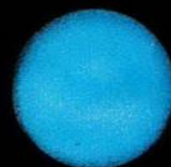
(M) Mars

Oct. 1 15
R.A. 14h20m 14h58m
Dec. -14°10' -17°15'
Mag. +1.7 +1.7



(C) Ceres

Oct. 1 15
R.A. 18h57m 19h09m
Dec. -30°42' -30°14'
Mag. +7.9 +8.0



(N) Neptune

Oct. 15
R.A. 17h00m
Dec. -21°19'
Mag. +7.7



SUN

The sun is within the stippled zone throughout the month. Planets and stars near this area are not easily seen.



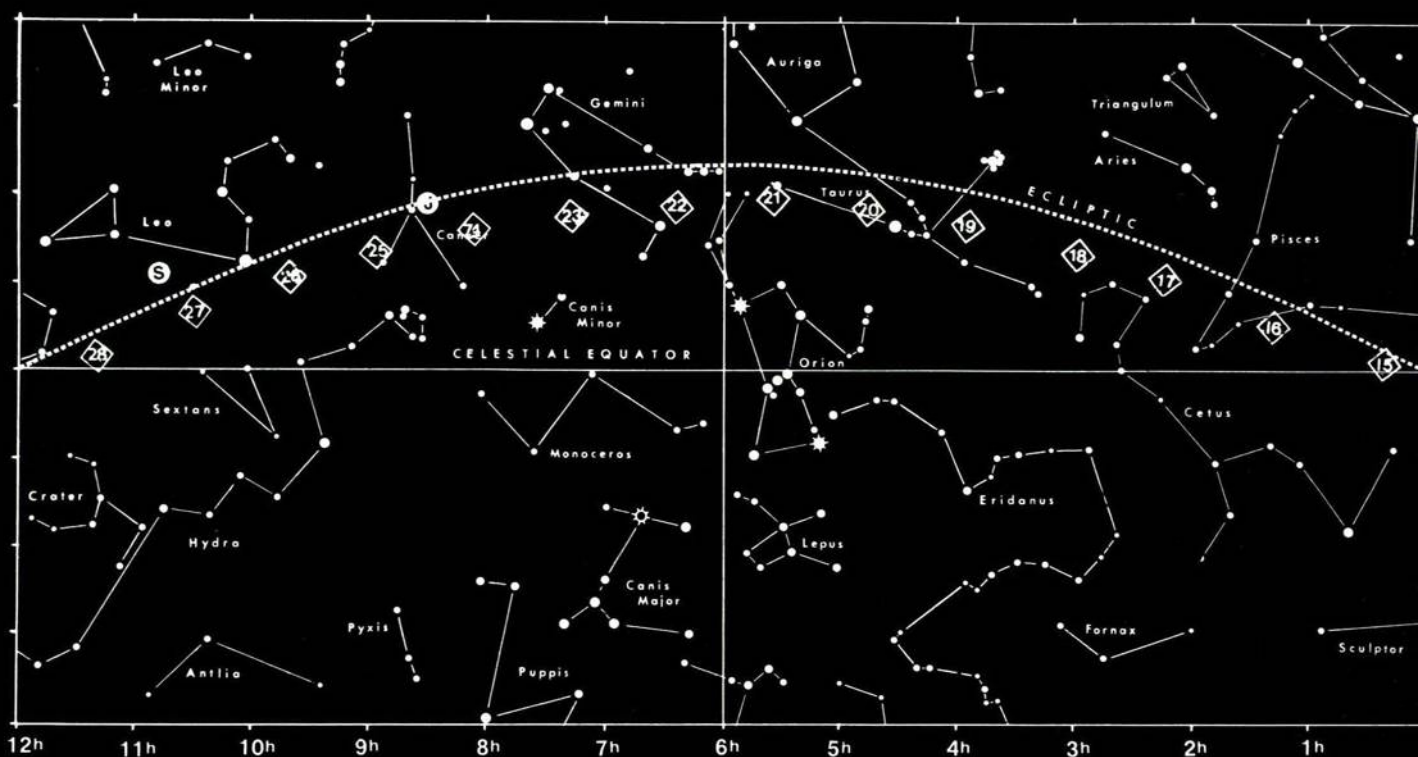
(S) Saturn

Oct. 1 15
R.A. 10h41m 10h47m
Dec. +9°53' +9°20'
Mag. +1.1 +1.1



(U) Uranus

Oct. 15
R.A. 14h51m
Dec. -16°03'
Mag. +5.7



The chart shows the positions of the moon, planets and brightest asteroids for the current month. Letters within the circles correspond to the letters beside each object in the data section above the map. Additional information about each object is given there. R.A. = right ascension and Dec. = declination, the two coordinates used to locate astronomical objects. The general coordinate system is indicated around the edge of the map. Mag. = magnitude, a

October 1978



(V) Vesta

Oct.	1	15
R.A.	17h37m	18h02m
Dec.	-24°20'	-24°52'
Mag.	+6.9	+7.0



(J) Jupiter

Oct.	1	15
R.A.	8h27m	8h35m
Dec.	+19°26'	+19°00'
Mag.	-1.6	-1.7



(Y) Venus

Oct.	1	
R.A.	14h54m	
Dec.	-22°32'	
Mag.	-4.3	

(Z) Venus

Oct.	15	
R.A.	15h13m	
Dec.	-24°51'	
Mag.	-4.2	



(P) Pluto

Oct.	15
R.A.	13h25m
Dec.	+8°51'
Mag.	+14



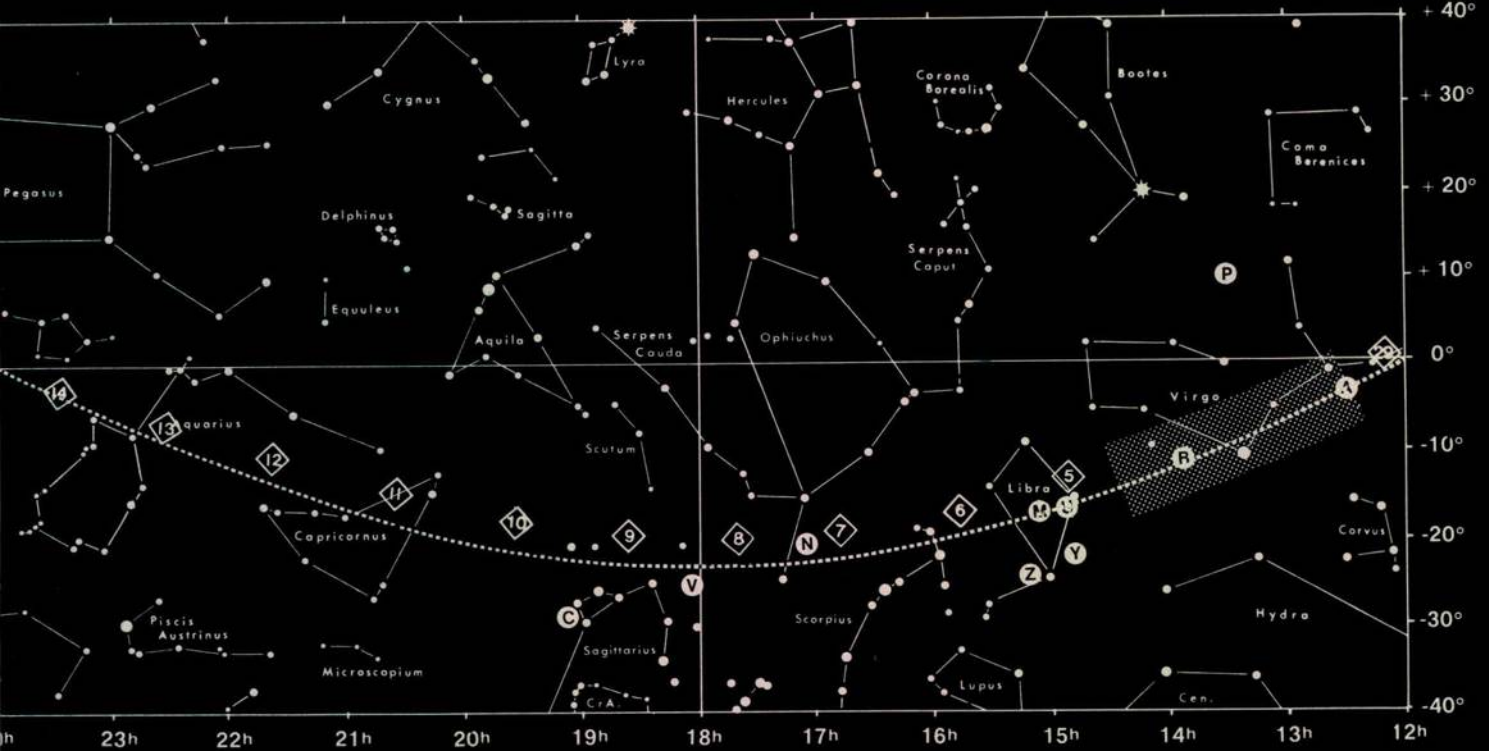
First Quarter
October 9



Full Moon
October 16



Last Quarter
October 23



measurement of the object's brightness. (The minus magnitudes indicate very bright planets.) The diamonds with numbers within them indicate the position of the moon for each day of the month; the numbers correspond to the dates. Positions of the planets are for the 15th of the month except for Mercury and Venus which are shown on both the 1st and 15th. Certain areas of this map and the Star Dome chart overlap each month.

The moon, Venus and Mars peek through the trees in this photo taken Aug. 7. Just above the moon is -3.7 magnitude Venus. Mars at +1.7 magnitude lies to the upper left of Venus. The darker part of the moon is glowing softly with Earthshine. Photograph by Joseph Coti.

enough to cast a distinct shadow, but on the 3rd the planet will be only 10 degrees or so above the horizon at sunset.

Through a telescope you'll see a slim crescent about 40 seconds of arc across. Even a pair of binoculars — if they're of excellent optical quality — will show a nonstellar image. Try looking during twilight when the glare of the planet is minimized by the bright sky.

By the end of the month, Venus will have crept very close to the sun and won't be easily visible until late November, when it will be a morning object.

Mars

Mars is becoming lost in the evening twilight. Over the month it will transit the constellation Libra, and on the evening of Oct. 11-12, it will pass close to Uranus. Mars' magnitude is +1.7, so it isn't very prominent. To see the conjunction with Uranus, set up your telescope so you can see the horizon to the west-southwest. At sunset the two will be only about 11 degrees high, so be ready as it gets dark!

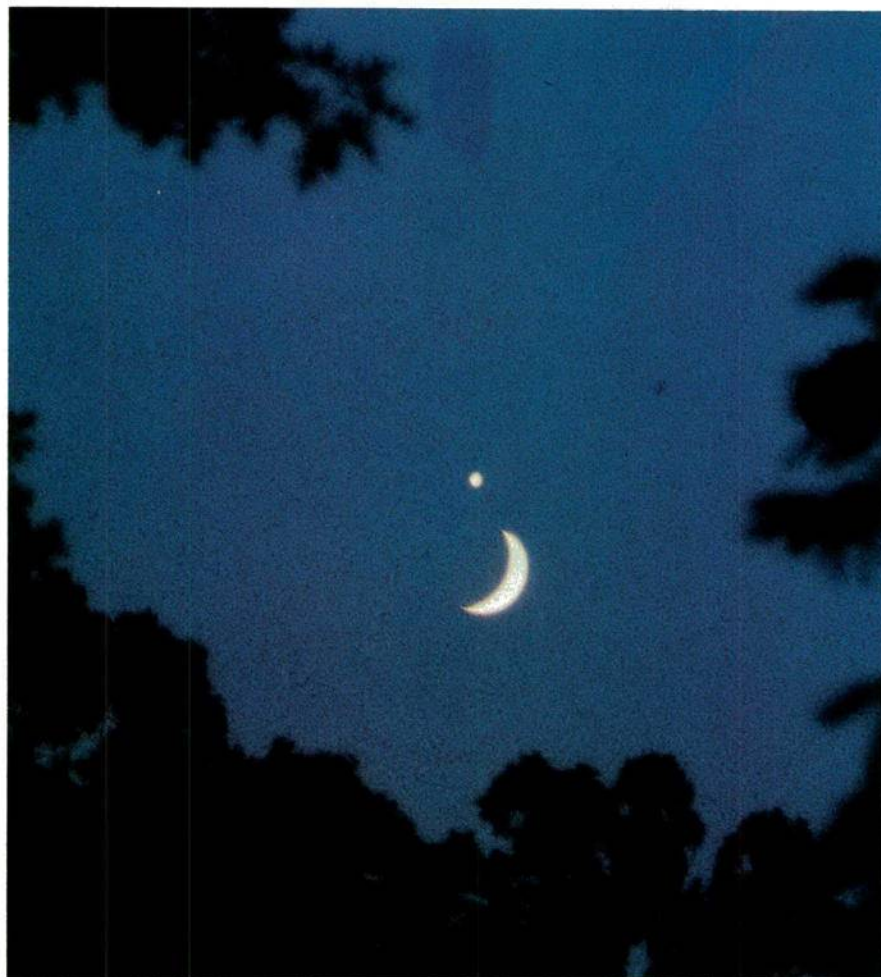
Mars will be a disk four seconds in diameter, meaning that all you'll see is a small round blob swimming in the soupy air. Uranus is at magnitude 6.0 and will be just 3.5 seconds across. (Use as high a power as the atmosphere will allow.) Since they will be about 1/2 degree apart, begin by centering Mars in a moderate power eyepiece. Then sweep to the north 1/2 degree and Uranus will be in the field. If you practice by locating both planets a few days before, you'll find it easier on the date of conjunction.

Jupiter

Jupiter is in Cancer for the whole month, and will be within a degree or three of the open star cluster M-44 (also known as the Beehive or Praesepe). Low power with your telescope or binoculars will show the passage south of the cluster very well.

Jupiter rises about midnight and is a fine object for the second half of the night. It's at magnitude -1.7 and the equatorial diameter is 35 seconds of arc.

If you watch Jupiter through a telescope for even a short time, you'll see evidence of its fast rotation. Since the planet spins around once in just under 10 hours, an hour's observation or less will clearly show some movement — especially if the Great Red Spot happens to be on the visible hemisphere.



The shadows cast on the globe of the planet by the moons are also fascinating to watch. Because all four of the Galilean moons circle the planet in less than a month, there are many shadow transits. For example, Ganymede — the largest of the four — will cast its shadow on the planet on the morning of Oct. 2. Callisto does the same on the 13th. Io and Europa, being always close to the planet, transit more frequently.

If you feel like challenging your skills a bit more, try to follow one of the moons itself as it transits the disk of Jupiter. Io can be seen crossing the disk on the mornings of Oct. 14 and 30. Ganymede will also transit on the 30th, but later than Io. Europa passes across the disk on the mornings of Oct. 19 and 26. Remember that you'll need a moderate sized scope (six inches or more) to see these passages with any clarity!

Saturn

In Leo this month, Saturn can be found about 10 degrees east of Regulus. It now rises some 3-1/2 hours before the sun and is a splendid morning object. One hour before sunrise on the 15th you'll find it 10 degrees south of east and about 28 degrees high, shining at magnitude +1.1.

On Oct. 16, the ringed planet will be

just 10 astronomical units away from Earth (930 million miles or 1,496 million kilometers). The ball of the planet then will be 15 seconds across, while the rings spread out to a diameter of over twice that — 37 seconds.

On Oct. 3, Saturn's brightest and largest moon, Titan — the one moon in the solar system known to have an atmosphere — will be at eastern elongation with the planet. This will also happen on the 19th. Its magnitude will be +8.5, and the separation from the planet will be 170 seconds of arc. Western elongations (which have the same separation and brightness) happen on the 11th and 27th. At magnitude 8.5, it's within range of binoculars; look for it on dates close to the elongations and try following it for a while!

When you look at Jupiter through even a low power telescope, you notice immediately that the planet bulges at the equator. Think of the rapid rotation and you'll see why Jupiter appears flattened at the poles. What's less often noticed is that Saturn is even more flattened than Jupiter!

Jupiter is always seen with the equator edge-on, making the bulge obvious. But with Saturn, the equator is tipped some 26 degrees to the plane of its orbit. This, and the distraction of

the ring system, means that only at intervals of about 15 years do you see Saturn's equator edge-on, clearly revealing the rotational flattening of the globe. This little fact tends to be forgotten during the years in between.

How can Saturn, with a slower rotation and smaller size, be more flattened? The answer lies in the amount of material that makes up the planet. Simply put, Saturn is less densely packed and much less massive than Jupiter, so the rotation (which is only 23 minutes less) has a greater effect on Saturn than it does on Jupiter, even allowing for its smaller size.

Uranus

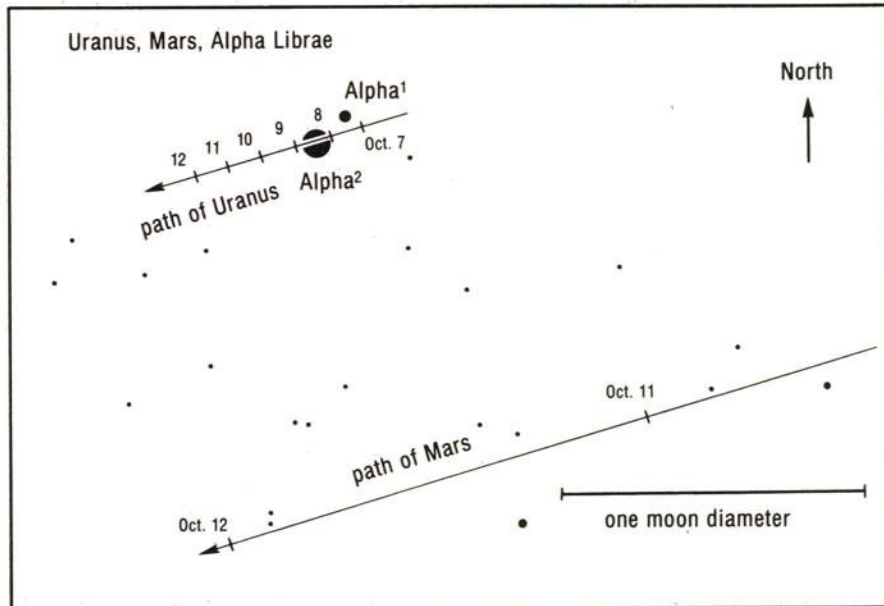
On the night of Oct. 7-8, 6.0 magnitude Uranus will slide between the two components of a double star, Alpha Librae. The star components are of magnitudes 2.8 and 5.2. But be aware that this rare event won't be easy to observe!

The problems are mainly due to the low elevation (12 to 13 degrees at sunset) and the bright light of the sky. The planet is in the west-southwest, and you'll do well to start following it — if you haven't been doing so all along — at least a few days in advance of the 7th.

You'll need a high power, but watch out for the blurring caused by the atmosphere! Uranus will show a disk about 3.5 seconds of arc across and will be easily distinguished from the stars, which are separated by some 230 seconds of arc. Good luck!

Neptune

Neptune is in southern Ophiuchus and will change its position less than one degree over the month. October is perhaps the last month for locating the planet with any ease because of the



approach of twilight to this part of the sky.

You can find it in binoculars, though a telescope is needed to show the 2.2 seconds wide disk. At midmonth it will be at magnitude +7.8 and lies about 4.5 degrees west of Xi Ophiuchi.

On Oct. 28, it'll be just 31 astronomical units from Earth (2.9 billion miles or 4.7 billion kilometers). The light you see reflected from it is 8.5 hours old, having left the sun, traveled 30 astronomical units out to Neptune and then come back to Earth over a distance of 31 astronomical units. Compare this with the mere 2.5 second round trip to the moon, and you begin to appreciate the scale of the solar system!

Orionid Meteors

The annual shower of the Orionid meteors peaks during the early

morning hours of Oct. 21, but the display won't amount to much this year because of the moon. Sitting in the part of the sky where the meteors will be, the light of the last quarter moon will wipe out most of them.

In good years, the average number you'll see is about 25-35 per hour. These meteors are fast (40 miles per second or 66 kilometers per second), so the loss of this year's shower is unfortunate. The radiant point is about halfway between Orion and Gemini.

Moon

The full moon this month (on Oct. 16) is called a Hunter's Moon. This is very similar to the Harvest Moon that occurs in September. While they have lost their great cultural and practical significance for most people, both moons are interesting to watch.

The effect you see is that of the moon rising only a little later each night when it is near full, providing light for human activities in the early evening. The importance of this for people living "close to the land" is obvious: When there are crops to harvest or game to be hunted, any extra light in the evening effectively extends the day.

The astronomical explanation for the phenomenon lies in the fact that in the fall, the sun is slipping south of the celestial equator at its maximum rate. At the same time, the orientation of the moon's orbit in space is such that it's moving to the north of the celestial equator at sunset. The effect is to speed up the time of sunset and hasten the time of moonrise, often making the moon rise only 20 minutes or so later each night. At times near the solstices when the rate of change in declination for the sun is minimal, the rising can happen as much as an hour or more later each night!

Upcoming Events for November

4 Taurid meteors	15 Mercury at greatest eastern elongation
5 Mercury close to Mars	16 Occultation of Aldebaran
7 First Quarter Moon	17 Leonid meteors
Venus at inferior conjunction	22 Last Quarter Moon
14 Full Moon	30 New Moon

This month offers many things: two meteor showers, an elongation of Mercury and another occultation of Aldebaran!

The Taurid meteor shower is one of the lesser ones occurring each year, with the single observer rate being about 15 to 20 per hour. It does happen at an auspicious time, though, with the moon setting early and leaving the sky to the meteors. The same can't be said about the other shower, however! The moon will pretty well wipe out the Leonids.

The elongation of Mercury is not one of the best ones, since the elevation of the planet above the horizon won't be very much. (We'll have a diagram showing the position of the planet relative to your horizon in next month's issue.)

The occultation of Aldebaran will be a repeat performance for the benefit of all who missed it back in September, and any others who want to see it again. The only observers in the continental United States who'll miss it are those living in the Florida peninsula.





PHOTOGRAPHY IN ASTRONOMY

Astrophotography With A Small Telescope

by

Richard Berry

If you own a small telescope — such as a 2.4 inch (60mm) refractor or a reflector in the three to four inch range — you might have thought that astrophotography was an adventure beyond your telescope's abilities. But it isn't! With no special equipment except the camera itself and a steady tripod to support it, you can obtain excellent pictures of the moon and, with a bit of luck, the bright planets.

The usual problem in astrophotography with a small telescope is that the weight and shake of the camera attached to the telescope causes the image to bounce around, so whatever pictures you do get are blurred. Often you need adapters and tubes to allow you to project or enlarge the image onto the film, as well as a single lens reflex camera. But there's one method of astrophotography that avoids most of these problems: *afocal* astrophotography.

The afocal method involves nothing more complicated than holding your camera up to the eyepiece of the telescope and taking a picture into it. If you're careful that the camera lens doesn't bump the eyepiece and shake the telescope, there's no vibration problem from the camera at all. No special parts are required aside from the eyepieces you already probably own. Furthermore, you can use the afocal method with the simplest or most sophisticated cameras available, although, as usual, single lens reflex (SLR) cameras have an edge in terms of ease of use. Even if you don't want to get serious about astrophotography,

The moon, one day past first quarter, was recorded with a four inch Astroscan telescope using the afocal method. The telescope was aimed at the moon while the camera — supported on a separate tripod — was aimed into the eyepiece. The total focal length of the system was 3,200mm — because a 200mm camera lens was used with a 16 power telescope. The exposure was 1/30 second on Tri-X film.

you'll find taking a few moon pictures is an enjoyable way to spend an evening from time to time.

What's involved? First, you'll have to set up your telescope in a place where the ground is solid enough that the telescope doesn't shake as you walk around. Secondly, for the best results, you'll need to place your camera on a tripod and adjust it to look into the eyepiece of the telescope. Next, you'll need to focus the image sharply on the film. This is easy with a single lens reflex camera and somewhat more difficult — though possible — with nonreflex cameras. Finally, you'll have to determine the exposure, and shoot. With the help of the table on page 35 — or even the old "try it and see" method — exposure shouldn't pose an insurmountable problem.

Let's discuss each step in detail.

Telescope Solidity

The greatest cause of poor pictures taken with telescopes is image motion, or telescope shakiness. You probably can't do very much if your telescope — whether large or small — is mounted on a spindly shaky tripod, with undersized castings or rubbery fork arms. With small telescopes, it's best to get the camera off the telescope and onto a separate support that doesn't communicate unsteadiness to the image. Make sure the ground where you set your telescope is firm; be sure the legs of the telescope rest on firm dirt, rock or concrete. Jump around a bit to see if your footsteps will translate into blurred pictures when you try astrophotography.

The telescope may, as some telescopes unfortunately do, shake when the wind blows. Make sure that you've assembled everything properly. If the telescope is still shaky, try draping a beanbag over the middle of the tube. Sometimes this extra weight helps damp out the vibrations in small refractors.

Finally, don't attempt astrophotography when the image you can see is turbulent, disturbed or "boiling". If a weather front has just come through, or you're trying to observe from a large asphalt parking lot that's been baking in the sun all day, don't expect steady seeing! Avoid looking across the roofs of houses: They're frequently hot, and warm air rising from them will disturb images all night. It's necessary for the telescope to come to air temperature before it can give its best performance. An hour outside — at least — usually suffices to bring small reflectors to air temperature.

Supporting the Camera

If you don't have a camera tripod now, and you have any interest in astrophotography, buy one. You'll need it for star trails, constellation pictures and photographing planetary conjunctions, as well as afocal photography with a telescope. Set the tripod beside the telescope and, using the adjustments on the tripod, bring the camera lens right up to the telescope's eyepiece so the camera is looking into the eyepiece. As the moon moves across the sky and you move the telescope to follow it, you'll need to reposition the camera from time to time. This is the greatest drawback of the afocal method, and it's quite annoying with long focal length refracting telescopes where the eyepiece swings through a long arc. With stubby telescopes like the Astroscan, it's hardly a problem at all.

Focusing

Focusing is simple if your camera is a single lens reflex. Looking through the camera viewfinder, focus with the normal telescope focusing knob until the image is sharp. Focusing is easiest and most reliable if you use the ground glass donut that surrounds the split image or micrometer focus screen on many brands of SLR cameras. When the image is sharp, take the picture.



Exposure for the Moon

Aperture	Telescope Power	Camera Lens Focal Length	Lunar Image Size	Resultant Focal Ratio	Crescent	Quarter	Gibbous	Full
60mm (2.4")	30x	50mm	1/2"	f/25	1/15	1/30	1/60	1/125
		100mm	1 "	f/50	1/4	1/8	1/15	1/30
	45x	50mm	3/4"	f/38	1/8	1/15	1/30	1/60
		100mm	1-1/2"	f/75	1/2	1/4	1/8	1/15
80mm (3")	40x	50mm	3/4"	f/25	1/15	1/30	1/60	1/125
		100mm	1-1/2"	f/50	1/4	1/8	1/15	1/30
	60x	50mm	1 "	f/38	1/8	1/15	1/30	1/60
		100mm	2 "	f/75	1/2	1/4	1/8	1/15
100mm (4")	16x	50mm	9/32"	f/8	1/125	1/250	1/500	1/1000
		100mm	9/16"	f/16	1/30	1/60	1/125	1/250
		200mm	1-1/8"	f/32	1/8	1/15	1/30	1/60
		400mm	2-1/4"	f/64	1/2	1/4	1/8	1/15
	32x	50mm	9/16"	f/16	1/30	1/60	1/125	1/250
		100mm	1-1/8"	f/32	1/8	1/15	1/30	1/60
		200mm	2-1/4"	f/64	1/2	1/4	1/8	1/15
		400mm	4-1/2"	f/128	1	1/2	1/4	1/8
150mm (6")	64x	50mm	1-1/8"	f/32	1/8	1/15	1/30	1/60
		100mm	2-1/4"	f/64	1/2	1/4	1/8	1/15
		200mm	4-1/2"	f/128	1	1/2	1/4	1/8
		400mm	9"	f/256	2	1	1/2	1/4

How to use this table: Find your telescope's aperture and the closest approximation to the power you will use. Select your camera lens, and then look at the exposure times listed on the rest of the line; from them, choose one appropriate for the lunar phase. Use ASA 400 film — either color or black and white. In general, you'll need a tripod to support the camera for exposures longer than 1/30 second.

Keep readjusting and checking the focus; one exposure will inevitably come out better than the others even when they all seemed equally well focused at the time you took them.

If you don't have a single lens reflex, you can focus by using a finderscope (or binoculars) as a focus checker. Begin by pointing your finder at a distant star and adjusting its focus to give a sharp image. Then point the finder (or binoculars) into the eyepiece and (without changing the focus of the focus checker) adjust the eyepiece to give the focus sharp image. Set the camera lens to infinity (or the "scenic" mark if it's a zone focus camera) and make your exposure. Because your eye can't be trusted to focus to infinity accurately, use the low power telescope to magnify any focus errors

for you. Focusing on this greatly enlarged image, you're certain to get a sharp image. It's fun, also, to aim one telescope into another! The power you'll get is the arithmetical product of the powers of the two instruments.

Taking the Picture

Once focused, check that the camera aperture is wide open (so all the light from the eyepiece can enter the camera), set the shutter speed, and shoot. The table above gives exposure times for various lunar phases and telescopes, assuming you're using ASA 400 film — either color or black and white. Fast film is essential with small telescopes because the image is relatively dim and vibration is a problem: The shorter the exposure, the better. Don't rely on only the exposure given in the table; try at least one longer and one shorter exposure. Keep a written record so you'll learn what exposures work best for you. And keep trying — your results will improve rapidly!

You'll notice that the table shows camera lens focal lengths other than the standard 50mm lens. Longer focus lenses let you get a bigger image without using higher power eyepieces. If you own these extra camera lenses, go ahead and try them.

A Few Extra Hints for Afocal Astrophotography

If you have a bigger telescope, or want to try different ranges of powers and focal lengths than given in the table, it's easy to make your own table. You can find the magnification (or

power) of any telescope from the following formula:

$$\text{Magnification} = \frac{\text{focal length of telescope}}{\text{focal length of eyepiece}}$$

Then, for afocal astrophotography, it's just one step more to find the focal length of the entire system:

$$\text{System focal length} = \text{Magnification} \times \text{focal length of camera lens}$$

The focal ratio, which you'll need to calculate the photographic speed of the system, is then found from:

$$\text{System focal ratio} = \frac{\text{System focal length}}{\text{Aperture of the telescope}}$$

Finally, use the following equation to find the image size for the moon from:

$$\text{Lunar image size} = \frac{\text{System focal length}}{115}$$

You can find the exposure time by evaluating the following equation, where S is the ASA speed of the film, f is the system focal ratio, and B is a brightness value for the moon: B = 10 for thin lunar crescents, 20 for wide crescents, 40 for quarter moon, 80 for gibbous, and 200 for full.

$$\text{Exposure} = \frac{f^2}{S \times B}$$

Further calculations and advice on finding exposure are found in "Exposure in Astrophotography", *ASTRONOMY*, August 1978. There you'll find more complete information to calculate the exposure times for the moon and planets, and a chart to find the image size of the planets.

Top left: The eight day old moon was filmed with a 60mm Sears refractor using the afocal method. A 23mm Huygens eyepiece gave a 30x image. The camera had a 50mm f/3.5 lens and was loaded with Verichrome Pan film (ASA 125); the exposure was 1/5 second. Photograph by Wayne Wolfe. **Top right:** The brilliance of the nearly full moon allows exposures so short that a tripod is not necessary. This 1/60 second exposure was made on Tri-X film (ASA 400) with a camera aimed into the 40 power eyepiece of a 60mm Sears refractor. **Bottom:** High resolution results from longer focal length. Here the system focal length was 6,400mm, achieved by using a 200mm camera lens aimed into a four inch Astroscan at 32 power. The exposure, on Tri-X film, was 1/4 second. Photographs by Richard Berry.

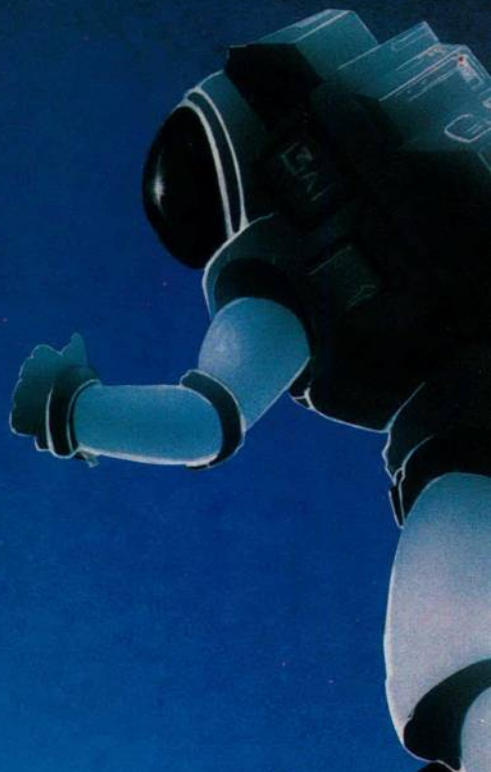
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Ht. 16-1/2" \$18.95@



The Lenox
Antique in appearance — yet up-to-date with today's world

This beautiful 12" raised relief globe is an excellent example of the fine art of mapmaking. Ocean areas resemble parchment and are decorated with old world cartouches and compass roses. Country colors appear as solids along boundaries and softly vignette toward the center, making all place names brilliantly legible. The traditional base and numbered half meridian ring have an antiqued fruitwood finish.

Ht. 18" \$27.95@



Official NASA Moon Globe

The 12" lunar globe was developed completely under the auspices of NASA, with all detail approved by them! It includes sites of the first U.S. and Russian unmanned landings, as well as our first Apollo manned landing. Highly legible names appear in Latin with English translations. The *NASA Moon Globe* is strikingly 3-dimensional in appearance, and rests on a molded base. Comes with "Story of the Moon" booklet, including interesting study projects.

Ht. 15" \$16.95@

Quantity	Item	Unit Price	Amount
	The <i>Apollo</i>	\$18.95	
	The <i>Lenox</i>	\$27.95	
	NASA Moon Globe	\$16.95	
		TOTAL	

Please charge to my: Mastercharge ☐ Bank Americard/VISA ☐ Date: _____

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Send check or money order to:

Account Number _____

ASTRONOMY

Personal Signature _____

411 E. Mason St. - 6th Floor
Milwaukee, WI 53202

Name _____
(please print)

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City _____ State/Prov. _____ Zip _____

Please allow 4 to 6 weeks for delivery.

Please remit in U.S. currency or equivalent.

First in its Class

The Meade 6" Model 591:

A High-Performance Lunar, Planetary, and Deep-Space Instrument for Visual or Photographic Applications.

Equipped as shown with: Electric Motor Drive, 2 Coated Eyepieces (threaded for filters), Setting Circles, 6 x 30 Viewfinder, Rotating Tube, and more.

Complete: **\$279⁵⁰**

f.o.b. Costa Mesa, Calif.
Packing charge: \$15.00

FREE! No. 51
Accessory
Case with the
purchase of Meade
Model 591 6" reflector!

The No. 51 Case provides dust-free protection for eyepieces, filters, and Barlow lenses; includes a strong, positive latch and die-cut foam lining. Sells separately for \$8.95.

All orders to receive free accessory case must mention this ad to qualify.

Compare the Meade Model 591 feature-for-feature with any other 6" telescope and we guarantee, in writing, that you will find it the finest value obtainable for under \$300.

- **6" f/8 Research-Grade Optical System** — The exact same optical system used on our more sophisticated 600-Series of 6" telescopes. 1/10-wave surface accuracy. There is no finer 6" optical system obtainable.
- **Fully Machined Equatorial Mount** — Includes the new Meade lightweight mount, the only equatorial mount in its price range machined to tolerances within .001", the accepted standard for long-exposure, high-resolution astrophotography. Polar and Declination shafts are 1" diameter solid steel, ground and polished.
- **Electric Motor Drive System** — With automatic clutch and precision-cut gear components, for accurate, completely automatic tracking of celestial objects.
- **Two Achromatic Coated Eyepieces, Threaded for Filters** — Kellner 9mm (135X) and 25mm (49X). And you can choose from over 20 optional eyepieces to suit your photographic or observing requirements, for powers from 30X to 350X.
- **Excellent Photographic Capability** — The Model 591 includes focal point settings for both first (prime) focus and eyepiece projection astrophotography, a feature not available on competing models. A wide range of lunar, planetary, and deep-space photography is within reach of the average amateur.
- **Setting Circles** — Finely indexed, for the location of faint objects directly from their celestial coordinates.
- **6 x 30mm Viewfinder** — Includes achromatic coated objective lens and crosshair eyepiece with excellent field corrections. Wide 5-degree field of view.
- **Rack-and-Pinion Focuser** — Helical-cut, chrome-plated brass drawtube, with 1 1/4" I.D. eyepiece holder. A strong, accurately machined focuser easily capable of holding 35mm cameras for astrophotography.
- **Fully Rotating Tube** — Permits comfortable viewing position in any telescope orientation. Strong, fiber-reinforced tube with attractive white finish and polished metal trim bands at each end.
- **Optional Accessories** — The widest range of auxiliary systems and accessories available for any 6" telescope in its price range, including variable-speed drive correctors, filters, eyepieces, 2" photo-guide telescope, camera adapters, and more.

A FRANK COMPARISON OF 6" REFLECTORS

There are other 6" telescopes in the price class of the Model 591, and while most 6" reflectors tend to look about the same in advertising photos, no competing model — not one — offers the precision machining, the uniformly high component quality, or the careful attention to detail of this Meade 6" telescope. The following discussion is as honest and straightforward a comparison as we feel can be made. No claims are made here that we cannot fully support.

Equatorial Mounts: Based on a sample we tested, one 6" reflector selling for about \$250 uses a roughly-machined polar axis, which is then "hand-punched" to fit the polar shaft — a crude practice on what is claimed to be a "fine instrument." The declination shaft of the same telescope wobbles in its casting unless literally locked in place. Meade equatorial mounts are fully machined on \$10,000 lathes to tolerances within .001", and are capable of the fine guiding absolutely essential for serious observing and quality astrophotography.

Eyepieces: The Kellner eyepieces supplied with the Model 591 yield apparent fields of view significantly wider than the Ramsden eyepieces supplied with

some 6" reflectors. Serious observers will also appreciate the filter thread provided on Meade eyepieces, compared to the unthreaded barrels supplied by some manufacturers.

Components: The curious amateur who disassembles his Model 591 for a closer look at the internal workings will be delighted with the intrinsic quality of the instrument.

Consider the three-ribbed mirror cell, with all the rigidity required to hold the 6" primary mirror in precise collimation; the beautifully machined focuser with helical gears, absent the annoying vibrations and wobble of focusers on competing

6" telescopes; the virgin aluminum castings, which produce tooled surfaces almost as smooth as glass.

In sum, if we seem to be proud of our 6" telescope, it's because we know the Model 591 is the best in its class by a wide, wide margin.

And we guarantee you will agree.

GUARANTEE

The Meade Model 591 is guaranteed to be the finest telescope—in every detail—of any 6" reflector in its price class. The purchaser of the Model 591 may return the telescope to us within 10 days of receipt, in its original condition and freight prepaid, for a full and immediate refund, if not completely satisfied with the instrument. This guarantee is valid whether the telescope is purchased by mail order, telephone order, or in our Costa Mesa showroom.



Research level telescope parts and accessories from America's No. 1 supplier to the serious amateur

1 - Series 1 KELLNER EYEPIECES (1 1/4" O.D.) — Highly corrected, 3-element design, fully coated. The best in moderately priced eyepieces. Barrels threaded for our filters. Focal lengths: 6, 9, 12, 25mm . . . each \$14.50 p.p.d. — 40mm Wide-Field . . . \$16.50 p.p.d.

2 - KELLNER 40mm EXTRA-WIDE-FIELD EYEPIECE (1 1/4" O.D.) — Yields widest field obtainable in 1 1/4" O.D. Enlarged field lens and special field-flattening optics with long eye relief. Barrel accepts our filters. \$24.75 p.p.d.

3 - Series 1 ORTHOSCOPIC EYEPIECES (1 1/4" or .965" O.D.) — Our most popular eyepieces, over 25,000 now in use. Classical 4-element design, 45° field, fully coated, with precise corrections for color and field flatness. All 1 1/4" barrels are threaded for our filters. Focal lengths: 4, 6, 9, 12, 15, 18, 25mm . . . each \$23.75 p.p.d.

4 - Research-Grade ORTHOSCOPIC EYEPIECES with Multi-Coated, Parfocal Optics (1 1/4" O.D.) — The largest-selling premium-quality eyepieces in the world, universally acclaimed to be the finest obtainable. These 4-element systems are unsurpassed in resolution, color correction, and flatness of field. Air-to-glass surfaces are 7-layer multi-coated for maximum image contrast and light transmission. 45° field. Precisely parfocal. Barrels threaded for our filters. Focal lengths: 4, 7, 10.5, 16, 8, 28mm . . . each \$38.95 p.p.d. Set of any 4 Research-Grade Orthoscopes . . . \$151.00 p.p.d. Set of any 4 plus Res. Grade Erle 20mm . . . \$193.00 p.p.d. Full set of 5 Research-Grade Orthoscopes plus Erle 20mm . . . \$229.50 p.p.d. (Sets of 4, 5, or 6 eyepieces are shipped in fitted carrying case — see #25 — at no additional charge.)

5 - Research-Grade ERFLE 20mm (1 1/4" O.D.) — Parfocalized with our Research-Grade Orthoscopes and 7-layer multi-coated. 75° apparent field for breathtaking wide-angle observations. Barrel accepts our filters. \$44.50 p.p.d.

6 - Zoom Kellner Eyepiece (.965" O.D.) — Fine 4-element design. Zoom range 7.5mm - 22.5mm. Fully coated optics . . . \$32.95 p.p.d.

7 - Zoom Orthoscopic Eyepiece (1 1/4" O.D.) — Zooms instantly from 8.4mm to 21mm, with excellent image corrections at all powers. Wide 50° field at 8.4mm. Fully coated optics. \$49.95 p.p.d. — Filter adapter #004 couples our filters to above eyepiece . . . \$1.00 p.p.d.

8 - Photo-Visual Color Filters — Top quality optical glass, dyed-in-the-mass, with excellent spectral homogeneity. Mounted in machined metal cells which thread directly into all our 1 1/4" "Series 1" and "Research-Grade" eyepieces. Filters may be piggybacked. Listed by Wratten No. and color: #8 Light Yellow - #11 Yellow-Green - #12 Yellow - #21 Orange - #23A Light Red - #25A Red - #47 Violet - #58 Green - #80A Medium Blue - Polarizer (30% transmission). Each filter: \$6.95 p.p.d. Set of any 6: \$39.50 p.p.d. — Full set of 10: \$64.50 p.p.d.

9 - VariPak Drive Corrector — This low-cost quality unit includes all the features required for the majority of guiding applications. New super-compact (2" x 3" x 4") design, with fast-slow pushbuttons mounted on the power pack. Variable control for lunar, planetary, sidereal rates. Operates from 12 volts D.C. The 8 watt output is sufficient for most telescopes to 10" aperture. \$59.95 p.p.d.

10 - VariGuide Drive Correctors — The finest R.A. drive correctors available. Each unit includes aircraft-type joystick controller for continuously

variable correction rates, not just "ON-OFF". Models 40 and 41 may be used with any motor-drive-equipped telescope rated up to 10 watts, including most commercial telescopes to 12 1/2" aperture.

Model 40 — Operates from 12 volts D.C. Control box includes variable center-frequency settings for lunar, planetary, sidereal rates. \$89.95 p.p.d.

Model 41 — Identical to Model 40, but operates from either 12 volts D.C. or 115 volts A.C./60Hz. \$119.95 p.p.d.

11 - VariGuide Dual-Axis Corrector Systems — For the advanced astrophotographer. Universal joystick controllers permit continuously variable correction rates simultaneously on both telescope axes. Each unit includes electronic control systems for both R.A. and Declination, along with all required mounting hardware. Models are available to fit Meade 600- and 800-Series reflectors and for the Celestron 5 and 8, as noted. After 15 minutes' installation, you will be using the most sophisticated and precise guiding system ever offered the serious amateur.

Model 47M — Attaches to Meade 600- and 800-Series reflectors. Operates from either 12 volts D.C. or 115 volts A.C./60Hz. \$215.00 p.p.d.

Model 47C — Attaches directly to Celestron 5" and 8" telescopes. Operates from either 12 volts D.C. or 115 volts A.C./60Hz. \$195.00 p.p.d.

RACK-AND-PINION FOCUSERS — Precision metal construction. All 3 models include helical-cut rack and variable-tension adjustment for ultra-smooth focusing without backlash. Universal bases fit all tube sizes. Standard 1 1/4" eyepiece holders. Each focuser is guaranteed to be the finest obtainable in its class.

12 - Model #67 — Strong, lightweight design for 4" to 10" telescopes. 2-3/16" travel. An excellent value. \$19.75 p.p.d.

13 - Model 640 — A heavy-duty deluxe focuser for 6" to 16" telescopes. Full 3" travel for both visual and photographic applications. \$33.95 p.p.d.

14 - Model 680 — Our finest focuser. Accepts both 1 1/4" and 2" eyepieces. Full 3" travel for photo or visual observing with 6" to 16" telescopes. \$39.95 p.p.d.

15 - Deluxe Camera Adapters — Adapt your camera to telescope focuser instantly. Individually machined from solid bar aluminum. All units permit both eyepiece-projection and first (prime) focus photography. Specify either .965" or 1 1/4" focuser. All 1 1/4" units are threaded for our filters. Pentax, Yashica, Mamiya . . . \$18.95 p.p.d. — Nikon, Canon, Minolta, Pentax K, Exakta, Konica . . . \$27.95 p.p.d. — Olympus OM-1, OM-2 . . . \$28.95 p.p.d.

16 - 2" First (Prime) Focus Adapter — For use with #680 Focuser or equivalent. Yields widest photographic field obtainable with 35mm cameras. For any of the above-listed camera brands (specify brand) . . . \$27.50 p.p.d.

VIEWFINDERS — Each finder includes coated, achromatic objective lens and crosshair eyepiece.

17 - 6 x 30mm — Fine, 4° wide-field finder. Thousands now in use. 2-ring bracket included, fits all tubes 6" to 12 1/2" . . . \$21.95 p.p.d.

18 - 6 x 30mm Right-Angle — As in (17), but with diagonal prism for convenient right-angle observations. Bracket included. \$27.95 p.p.d.

19 - 8 x 50mm — 5° field and large 50mm aperture. Sharp, brilliant images. \$33.95 p.p.d. Brackets: \$7.95/pr. p.p.d.

20 - 8 x 50mm Right-Angle — As in (19), but with diagonal prism. For both straight-through and right-angle viewing. \$39.95 p.p.d. Brackets: \$7.95/pr. p.p.d.

2" O.D. SUPER-WIDE-FIELD EYEPIECES — Premium-quality wide-field eyepieces for 2" focusers. The ultimate in rich-field performance. Fully coated.

21 - ERFLE 32mm (2" O.D.) — Sophisticated 5-element optical system. Wide, flat 65° field . . . \$94.50 p.p.d.

ERFLE 32mm (1 1/4" O.D.) — As above, but 1 1/4" O.D., 60° field . . . \$94.50 p.p.d.

22 - KELLNER 60mm (2" O.D.) — Low power, long eye relief. Ideal for deep-space observations . . . \$49.50 p.p.d.

23 - 2X and 3X TELENEGATIVE AMPLIFIERS (1 1/4" O.D.) — Warranted, without qualification, to be the world's finest Barlow lenses. Full 26mm clear aperture, with virtually flawless optical corrections at all photo-visual wavelengths. Produces optimum performance on telescopes of any focal ratio. Fully coated. 2X Model 122 . . . \$29.50 p.p.d. — 3X Model 123 . . . \$32.50 p.p.d. — Combination 2X and 3X Model 124 . . . \$39.50 p.p.d.

24 - Fiberlite telescope tubes, mirror cells, spiders, primary mirrors from 6" to 12 1/2" diameter, secondary mirrors, and objective lenses are available for immediate shipment. (Phone, or request catalog, for details.)

ACCESSORY CASES — Rugged polyethylene, for dust-free protection of eyepieces, filters, Barlows, etc. Die-cut foam lining.

25 - Model #51 — 7" x 8 1/2" . . . \$8.95 p.p.d.

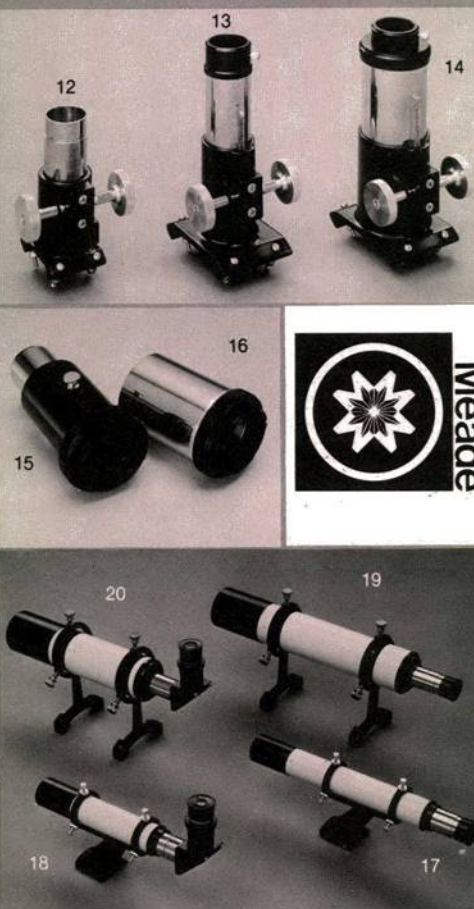
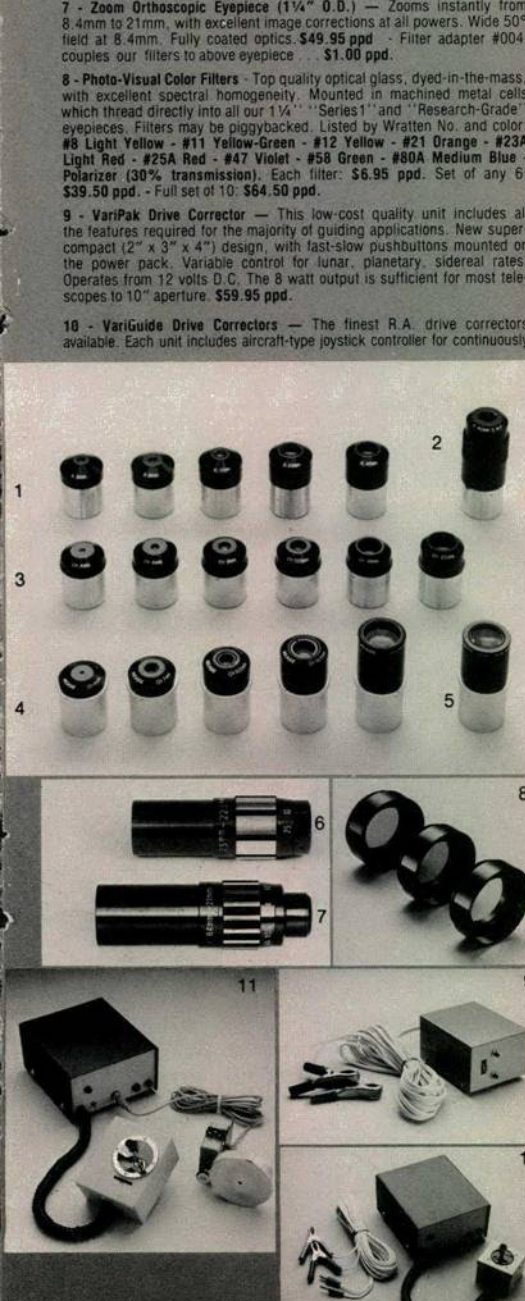
26 - Model #54 — 8" x 12" . . . \$12.95 p.p.d.

27 - ILLUMINATED RETICLE GUIDING EYEPIECE (1 1/4" or .965" O.D.) — For professional-level photographic guiding. Kellner 12mm optical system, with precisely focusable 4-line glass reticle. Remote brightness control and 3 ft. cable. (Extension cables available.) Complete . . . \$44.95 p.p.d.

Micrometer Reticle: Full-field scale for accurate measurements of double star separations, planetary angular diameters, etc. Interchanges with standard 4-line reticle . . . \$14.95 p.p.d.

28 - ERECTING PRISMS — Fully coated Porro prisms, for terrestrial observations with astronomical telescopes. 1 1/4" O.D. . . . \$29.95 p.p.d. — .965" O.D. . . . \$19.95 p.p.d.

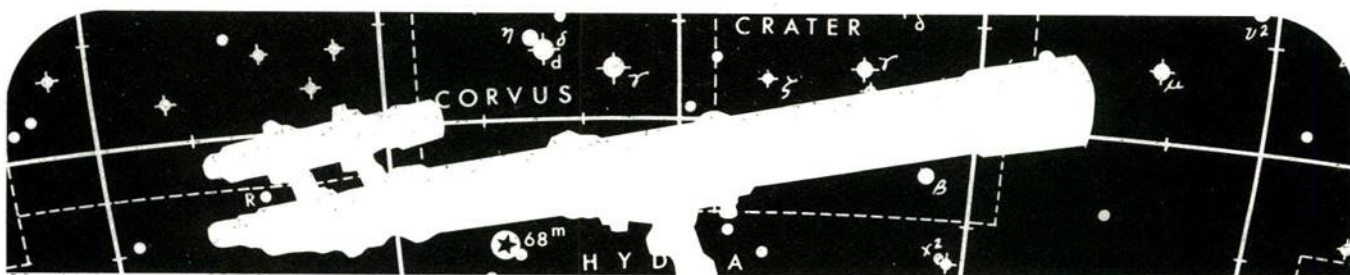
29 - DIAGONAL PRISMS — Quality right-angle prisms, fully coated. 1 1/4" O.D. . . . \$19.95 p.p.d. — .965" O.D. . . . \$14.95 p.p.d.



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Telephone Orders: Accepted with payment either C.O.D. or credit card (we do not accept collect calls).
Payment: Personal or bank check, money order, or credit card (BankAmericard/VISA or Master Charge).
Shipment: All orders are processed for shipment within 24 hours.
California Residents: Add 6% Sales Tax. Canadian Orders: Add 10% to cover priority mail charges.
Foreign Orders (Outside North America): Add 20% to cover Air Parcel Post charges — any excess will be refunded. Payment must be made by bank check in US \$.
General Catalog 78-C — \$1.00 (Outside North America \$2.00 for Air Mail). (Catalog free with any order.)

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Meade Instruments Corporation 721 W. 16th Street, Costa Mesa, Calif. 92627 (714) 646-9281



EQUIPMENT ATLAS

Build Your Own First Telescope

by
Richard Berry

You may not own the telescope you'd like to own. Or perhaps you'd like your children to have the thrill of seeing the moon and stars close up. After perusing the advertisements and checking your budget, hoping, wishing and then heaving a sigh, you might have decided that telescopes just cost too much.

Well nothing in the world is free, but you can build a telescope for just over \$60 that should perform to the theoretical limits if you put it together with reasonable care. Our design for a home built telescope and mounting doesn't take a carpenter's skill to execute. It uses inexpensive, conveniently available parts and hardware, and you can build it with a few basic tools.

The mechanical parts are made from pipe you can get at any hardware store, and wood. The primary and secondary mirrors, eyepiece holder and eyepieces were purchased ready made from mail order. The tools you'll need to assemble it are a handsaw, drill, screwdriver, pliers, sandpaper and paintbrush.

The completed telescope is an

equatorially mounted inverted fork design. It's lightweight, simple enough for a child to use, and powerful enough to introduce an adult to the wonders of the skies. Yet you can build the entire instrument in just three or four evenings in your own home!

Start by ordering the optical parts from one of the suppliers listed in the box on this page. You'll need a 4-1/4 inch f/10 spherical mirror and an elliptical diagonal mirror with a minor axis of about one inch. (Some suppliers offer lenses to make an eyepiece also, but you don't need those.) Next, order an eyepiece holder; it doesn't have to be one of the best — a simple basic plastic one will do quite nicely on this design. Order a diagonal supporting stalk with the holder; though these are not the best way to hold your diagonal mirror, they're good enough. Save the frills for your next telescope!

Last, order an eyepiece. The f/10 focal ratio of the mirror does not show up the faults of eyepieces; even a simple Ramsden will perform well. Start with a low power eyepiece; a 25mm, or one inch focus eyepiece, will give 45 power with this telescope. A second eyepiece (optional) might be medium power; one of 10mm focus is fine and will give you 100 power.

With the specialized parts on their way to you via the U. S. mails, you can begin to buy the materials for the tube and mounting. First you'll need the "precision equatorial bearings" — 1-1/4 inch standard pipe fittings. You'll need a tee, two close nipples, one 12 inch nipple, and two floor flanges. These parts will cost around \$10, unless you've got an uncle in the plumbing business. You can use smaller pipe, but at some sacrifice in rigidity of the mounting.

In a hardware store, purchase four U-bolts that fit around the pipe (it's a good idea to check this in the store!). As you can see from the drawings, the U-bolts really hold the telescope mounting together. Buy the small parts listed on the drawings — the little screws, bolts and other stuff. All

the hardware should cost less than \$5.

Finally, visit the lumber yard and pick up a 2x4 foot sheet of 1/4 inch plywood and a 2x4 foot sheet of 1/2 inch plywood. Also buy 16 feet of 3/4 inch quarter-round molding (it needn't be one piece since it's only the corner reinforcing for the tube of the telescope). Wood prices are variable, but you'll probably escape for under \$10.

Study the plans on pages 43 and 45 carefully. Figure out how the parts go together and what they are for. If you're handy with tools and woodworking, you may want to modify the plans somewhat for a little more elegance or simply to accommodate materials you happen to have on hand. Carefully lay out the plans full scale on the wood, and cut out the parts. Trim, smooth, fix up the edges, and sand them. Take enough time to do a good-looking job. When making parts that are used in pairs, make sure that they match each other closely.

It doesn't matter whether you start with the telescope tube or the mounting. The tube is more of a thrill to work on though! Cut the quarter-round stock to length. Nail and glue it to the narrow sides of the tube using a good wood glue such as Elmer's Carpenter's glue and small brads or finishing nails. Glue in the front end ring, but only tack the back end piece in; then glue and nail on the bottom of the tube. Leave the top of the tube off until later.

File, sand, or plane the mirror cell parts until they are a very close fit inside the tube. After drilling the holes and installing the tee-nuts in it, glue and nail the rear cell plate into the tube. Glue in the reinforcing ring. After the glue is thoroughly dry, paint

These plans show you how to cut and assemble the major parts of a four inch f/10 reflecting telescope. Nothing beyond ordinary hand tools are needed for the work, and no unusual skills are required. The telescope is made mainly from plywood panels, and the optics were purchased ready-made for about \$30.

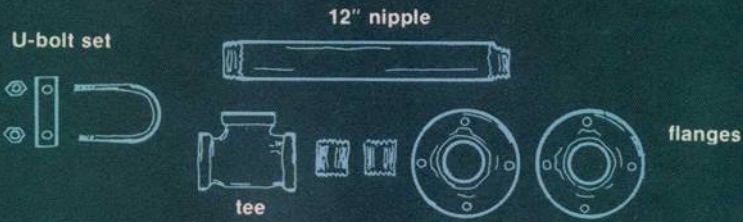
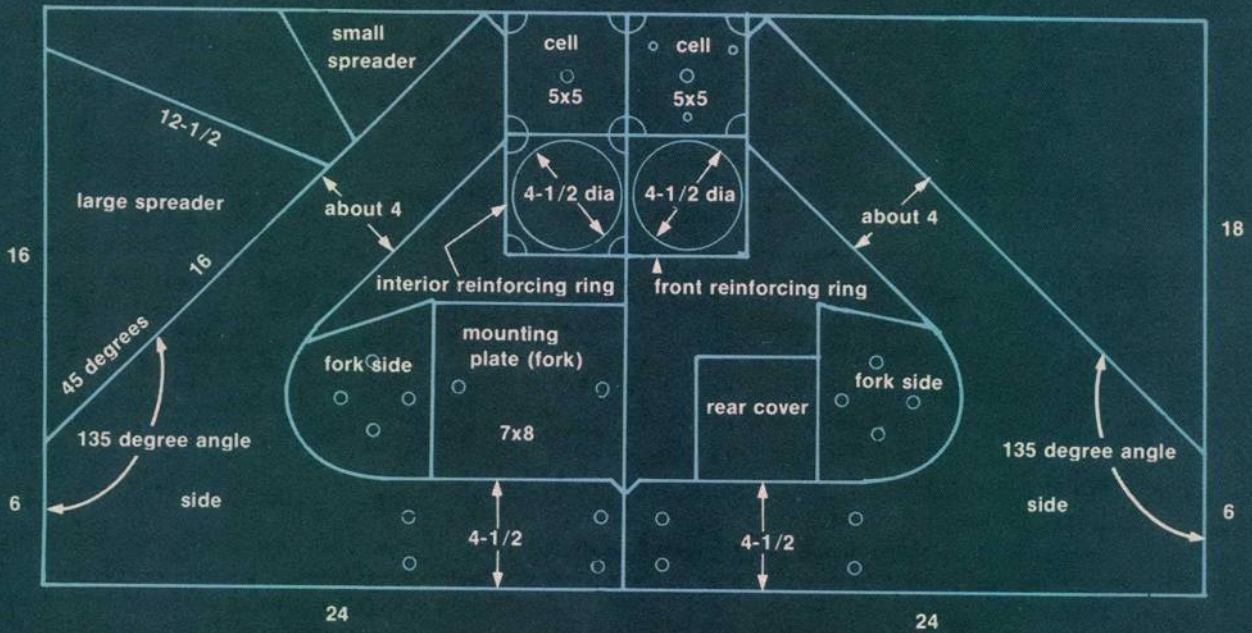
Edmund Scientific Co.
101 E. Gloucester Pike, Dept. A
Barrington, N.J. 08007

- ★Slide focus eyepiece holder
No. 60,067 \$5.75
- Diagonal and rod assembly
No. 60,086 \$8.25
- ★Ramsden eyepiece, 1"
No. 30,194 \$8.75
- Rack and pinion focuser
No. 50,077 \$15.50
- 4.25" f/10 mirror
No. 50,051 \$37.50

A. Jaegers
691 Merrick Road
Lynbrook, N.Y. 11563

- ★Reflector kit (both mirrors)
Cat. #2285 \$30.50
- 4.25" f/10 mirror only
Cat. #1506 \$25.00
- Rack and pinion focuser
Cat. #1976 \$14.00
- ★Diagonal holder
Cat. #2578 \$1.50

24"x48" sheet of 1/2" plywood



24"x48" sheet of 1/4" plywood





the interior of the tube and the top piece (which is not yet attached) with flat black paint. Acrylic spray for ornamental iron railings works very well. Bolt the eyepiece holder on when it arrives.

Drill the holes and cut the recesses for the U-bolts into the main base panels. Then assemble them with the 12 inch nipple in place. Tighten the nuts bolts on the U-bolts tightly — you should hear the wood creak! Glue and nail the large and small spreaders in place, and run a bead of glue down the long joint between the two main base panels. You could shape a piece of one inch semi-round to fit along that joint for appearance's sake, but it's not shown in the plans.

The inverted fork parts should be fit to the width and dimensions of the pipe flanges. The distance from flange to flange will be close to seven inches, but will vary depending on your pipe. The flanges should be threaded on far enough that they turn with moderate difficulty. Assemble these parts with wood screws — but no glue — so that you can readjust them later as the pipe threads wear in.

The primary and secondary mirrors can be glued in place if you use a strong (yet flexible) glue such as Pliobond. Be sure to read the directions that come with the glue!

First saturate the felt with glue and allow it to dry. Then coat the cell with a thin layer of glue, and recoat the felt. Allow them to dry until they are sticky to the touch and then bring them together. They will adhere tightly on contact. Next, coat the felt and mirror with a thin layer of glue. Let it get sticky; then bring the parts into contact. The brads (shown in the drawings) help you put the mirror in place when you glue it. Let the glue dry for a day before using the assembled parts.

Finally, assemble the telescope: Put the mirror and its cell into the telescope tube, install the diagonal, screw the top of the tube onto the rest of the tube (use small wood screws for this), and you're almost ready to go! Tilt the diagonal (by gently bending the metal stalk) so that the primary mirror reflection is fully caught in it, and align the primary so it shows the secondary image centrally (consult a book such as Edmund's *All About Telescopes* for more detail).

The tee-nuts in the tube (shown in the drawings) allow you to attach and detach the tube very easily from the mounting. For ease in carrying it, you may wish to add handles to both tube and mounting — making sure, of course, that the handles don't get in the way of anything. For storage when not

The completed four inch f/10 telescope is light and easy to carry outdoors to set up. It's an ideal instrument to build as a father-and-son project, or for a beginning astronomy enthusiast, without spending a lot of money. Despite its "no frills" appearance, it gives excellent performance on all the basic sights in the sky.

in use, wrap the telescope in a large plastic bag to keep it clean and free of dust.

The parts may be finished any way you like, with clear varnish, stain or paint. Generally, lighter colors make it easier to see the tube in the dark, and are preferable.

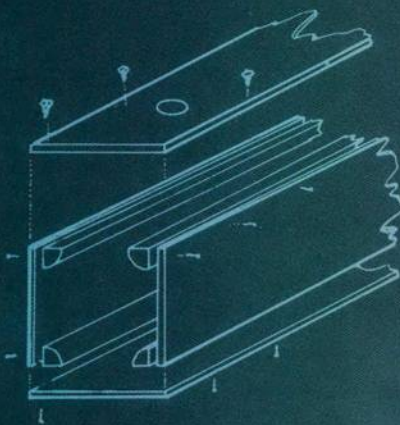
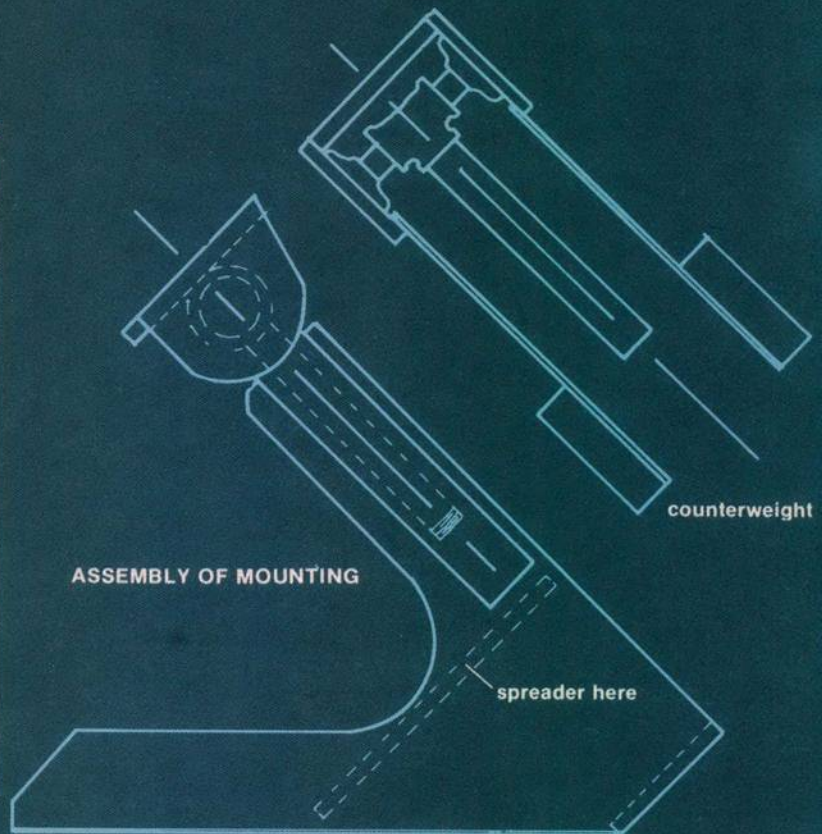
This telescope performs very well. The images are superb even at extremely high powers like 250x: The moon will be brilliant and crisply defined, and double stars will be resolved to the theoretical limit. At high powers, however, such a lightweight mounting is not as solid as is desirable. If you wish a maximally solid mounting, substitute 3/4 inch plywood for the 1/2 inch described, and purchase 1-1/2 inch pipe instead of 1-1/4 inch. ♦

More pictures and additional details about the design of this telescope will appear in the first issue of TELESCOPE MAKING.

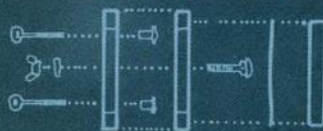
BILL OF MATERIALS

— HARDWARE —

- 2 1/4-20x1/2" tee nuts
- 3 10-24x1/4" tee nuts
- 2 1/4-20x1-1/2" thumbscrews
- 3 10-24x1-1/2" thumbscrews
- 1 1/4-20x2" stovebolt
- 1 1/4-20 wingnut
- 4 U-bolt sets to fit pipe
- 24 3/4" F.H. woodscrews
- 6 1-1/2"-#8 F.H. woodscrews
- 1 box 3/4" wire brads
- 2 dozen 2" finishing nails
- 4 nut and bolt sets for focuser
(will be included)
- 2 1-1/4" floor flange pipe fittings
- 2 1-1/4" close nipple pipe fittings
- 1 1-1/4" tee pipe fitting
- 1 1-1/4"x12" pipe nipple
- 2 counterweights (shop scrap or
short lengths of pipe)



mirror cell (exploded)



mirror cell (assembled)



side

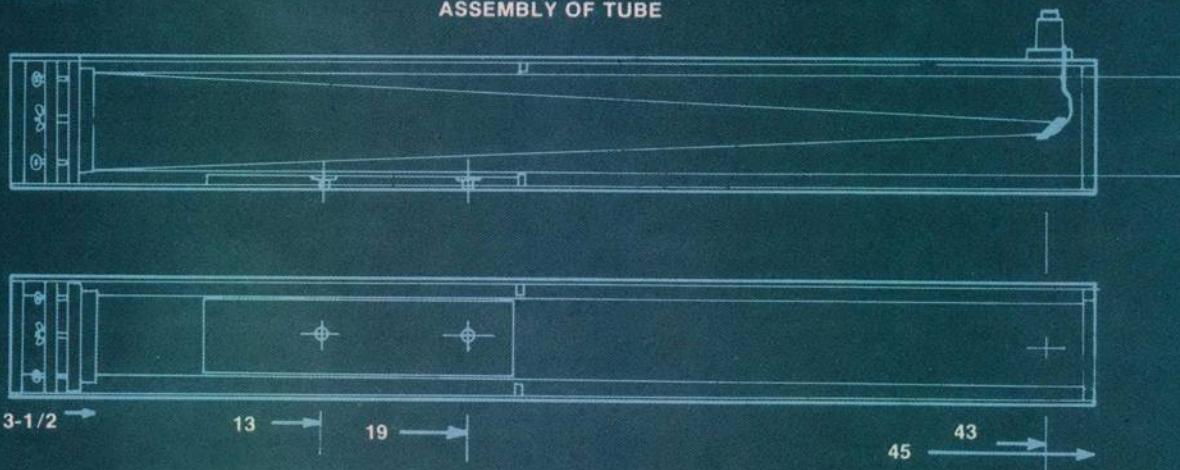


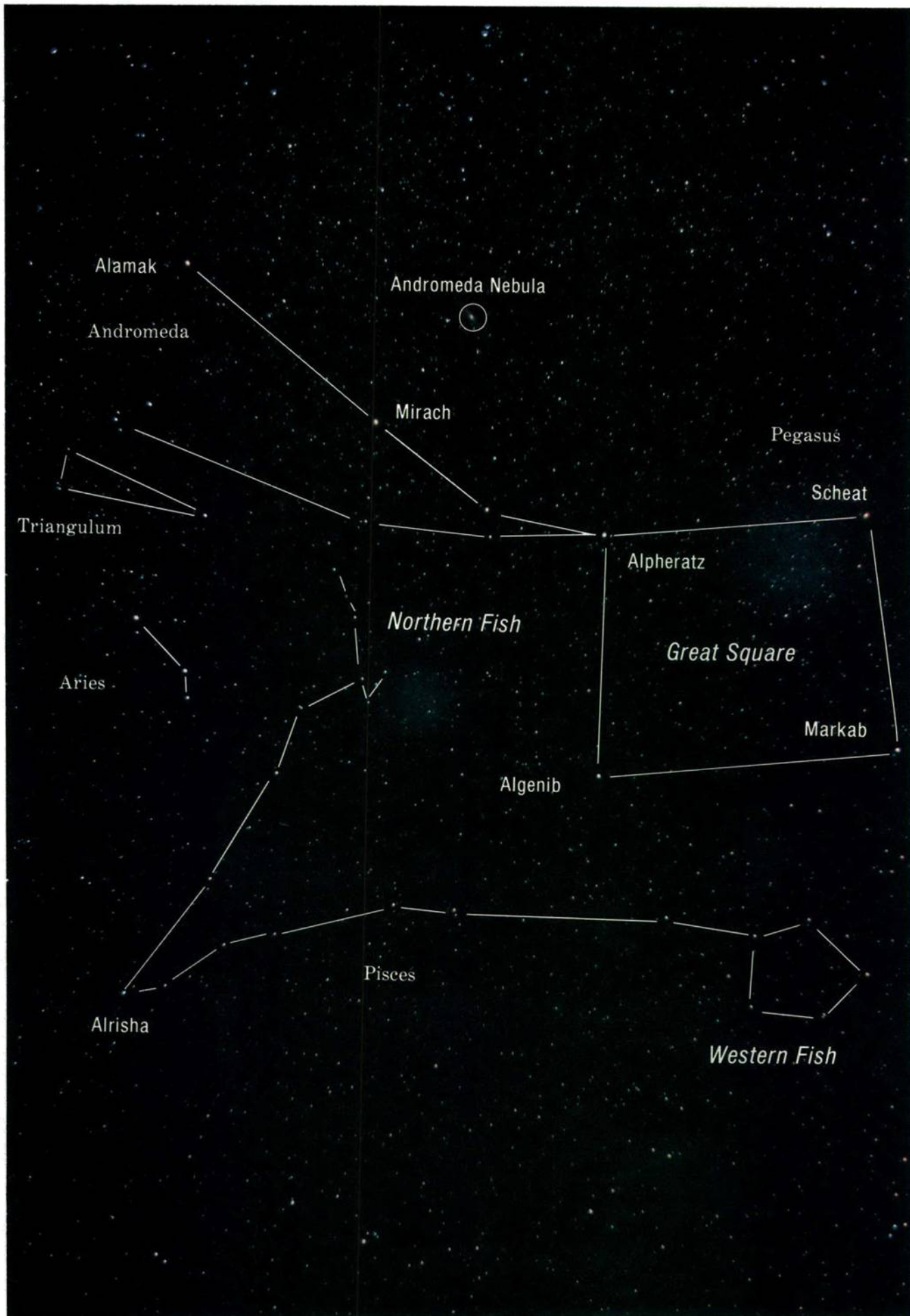
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back

ASSEMBLY OF TUBE







Learning the Constellations

Part 4: Autumn

by
Robert Burnham

The autumn constellations, along with those of spring, have something of a reputation for dimness and obscurity. This is a bit unfair because, although they do require a dark sky to trace them fully, they all stand out pretty well. In addition, they have more of an organic unity than those of the other seasons since they fall mostly into one of two groups.

The first group of six constellations is concerned with a mythological hero who rescued a fair maiden from a terrible monster (her parents and the hero's horse are also there). The second group, containing five constellations, amounts to variations on a water theme. The five figurations are all involved to some extent with water or the sea, and have connections with two other constellations in adjoining seasons.

If you go out around 9:30 p.m. on a mid-October night, the constellation **Pegasus** (PEG-uh-sus), the flying horse, will be high in the south. The most recognizable part of the constellation is the

so-called Great Square. Look for a rough square of second or third magnitude stars measuring about 15 by 18 degrees. Though the square is "of Pegasus", only three of the stars officially belong to the constellation. The fourth — the one at the upper left corner — belongs to Andromeda, so we'll mention it later.

The three Pegasus stars (clockwise from the upper right) are *Scheat* (shay-AT), *Markab* (MAR-kab) and *Algenib* (AL-jen-ib). Pegasus is one of the many constellations whose resemblance to its supposed shape is rather remote, but in the names of the stars you can often pick out a description of sorts. Scheat means "the horse's shoulder"; Markab means anything that is ridden or sat on, and Algenib is derived from words meaning "side" or "wing". This is a pretty peculiar horse! (By the way, if you watch for a few weeks, you may notice that Scheat's brightness appears to change slightly. Don't be surprised; it's a variable star that swings between magnitudes 2.2 and 2.8.)

The rest of Pegasus extends to the west (right), with his hind legs going up to the right toward Cygnus; his downbent head and neck are to the southwest. The brightest star here is *Enif* (EE-niff), which appropriately means "the nose". In some legends Pegasus is the horse of Perseus.

Going back to the Great Square, look at the

The Great Square of Pegasus and the sweep of Andromeda are telltale signs of autumn. Note the Andromeda nebula tucked away inside the curves of the Chained Lady. Triangulum — despite its seeming ambiguity (after all, any three stars make a triangle) — is one-of-a-kind among the constellations. Pisces the fishes, part of the zodiac, is much harder to find — but once you've found it, it's hard to forget. Another zodiacal constellation seen here is Aries the ram. Photograph by Brad Wallis and Robert Provin.



upper left corner star. This is *Alpheratz* (AL-fer-ATS), occasionally called *Sirrah* (SIHR-rah). The more popular name means "horse's navel", but when the constellation boundaries were formally established in 1930, this star (which had been shared jointly by Andromeda and Pegasus) went to Andromeda, and now represents her head.

Andromeda (an-DROM-e-da) was the mythical fair maiden and the center of a legend involving many of the constellations in this part of the sky: Cepheus, Cassiopeia, Perseus and Cetus. Andromeda has three bright stars that help you see the extent of the grouping. Start with *Alpheratz* and go toward the northeast. You'll see *Mirach* (MYE-rak) and *Alamak* (ALLA-mak) extending off from the Great Square in that order. *Mirach* (magnitude 2.4) is supposed to be Andromeda's left hip, and *Alamak* (magnitude 2.3) is her left foot.

Look several degrees to the upper right of *Mirach*, and you'll see an oval patch of haze. This is the most distant object the naked eye can see. Known as the great galaxy in Andromeda, it's a huge spiral like the one our sun is in. A pair of binoculars will show a slightly greater halo over what your eyes alone can see, but long exposure photographs are necessary to bring out much detail.

Continuing along a line starting with the square and going through Andromeda, you'll come

Above: The glories of the Milky Way run only slightly dimmed through Cassiopeia. Easily found by its distinctive W (or M) shape, the constellation never sets for viewers in midnorthern latitudes, and rides around the pole almost directly opposite the Big Dipper. Photograph by Stephen A. Walther.

to **Perseus**, a lovely constellation in the Milky Way. In mythology, Perseus (PURR-see-yus) was the hero who rescued Andromeda from being devoured by the terrible monster Cetus after she'd been chained to a rock. The constellation is well-concentrated and lies between Auriga on the east and Cassiopeia to the west.

Confusingly, the brightest star in Perseus is called *Algenib*, and like the one already mentioned in Pegasus, this one means "side" also. Perseus has a famous star which the Arabs named *Algol*, the demon star. You'll find it if you look for a second magnitude star about 10 degrees south and a little west of *Algenib*.

Algol is really two stars orbiting each other, but they're so close together they appear as one even in the largest telescopes. However, because the plane of their orbit lies in our line of sight, the dimmer star sometimes covers up the brighter, dropping the total magnitude from 2.3 to 3.7 in about five hours. Staying at minimum light for about a half hour, it then rises back to 2.3 again over five hours. Can you spot it?

In the northwestern part of the constellation,

most of the way toward Cassiopeia, there's the Double Cluster, which represents Perseus' upraised sword hilt. Look for an elongated fuzzy patch of light in the Milky Way. This is two clusters of stars formed in a group. If you have binoculars, you can make sure you've spotted it and additionally enjoy the fine views to be had by sweeping through the constellation with them.

Cassiopeia (KASS-ee-oh-PEE-yah) is found easily by looking for a W-shaped group of stars almost directly overhead. In the legend Cassiopeia was the mother of Andromeda, and is represented as being seated on a chair.

The brightest star is *Caph* (KAFF), magnitude 2.42, at the tip of the right side of the W. *Caph* is supposed to be the chair back. The next brightest star is *Schedir* (shed-EER), meaning the breast, at the bottom of the W's right side.

(In 1572, Tycho Brahe saw what we now know to have been a supernova in this constellation, thus disputing the Ptolemaic doctrine that the aspect of the stars was unchanging.)

Just north of the Milky Way is the constellation of **Cepheus** (SEE-fee-yus). Use *Caph* and *Schedir* as pointers to find Cepheus as far to the west of Cassiopeia as Perseus is to the east. Cepheus was the father of Andromeda. The constellation, however, resembles a stylized house with the gable pointing roughly at the pole star.

At the lower right corner of the house is *Alderamin* (ALL-der-AH-min), the right arm, a white star of magnitude 2.6. At the lower left corner, a bit to the east of the two or three stars making up the corner, is *Delta Cephei*, a well-known variable star. Its magnitude doesn't change much (from 4.1 to 5.2 in 5-1/3 days), but this star is the prototype of a class of variables used to determine distances to the nearest galaxies.

Between Cassiopeia, Cepheus, Cygnus, Pegasus and Andromeda is a little spray of stars all fourth magnitude or fainter. This is **Lacerta** (la-SER-ta) the lizard. It really does look like a lizard if you imagine that the group represents him wiggling along in a north-south direction. None of the stars have common names and, in fact, the constellation is a relatively recent one, having been formed by 17th century astronomer Hevelius to fill an otherwise empty part of the sky.

If we go back to Persus and look to the southwest a bit, you'll see a small, somewhat inconspicuous triangle of third magnitude stars. This is **Triangulum** (TREE-ang-gul-um). It isn't very large or even striking, but the constellation goes back far into antiquity. The brightest star is *Beta Trianguli*, at the corner nearest Andromeda. The one star with a common name is in the southwest corner: *Metallah* (meh-TAHL-ah), meaning the triangle.

It was in this constellation, in 1801, that the first of the minor planets, Ceres, was accidentally found. If you have a clear, moonless night, look just

to the west of the triangle for a largish faint patch of light. If you see it, you'll be looking at another distant galaxy, similar in some ways to the Andromeda galaxy, though this one is seen more nearly face-on.

Below and to the east of Triangulum lies the constellation **Aries** the ram. Aries (AIR-eez) traditionally is the first constellation in the zodiac, because when the constellations were laid out and the zodiac described, the sun crossed the celestial equator into the northern hemisphere (marking the start of spring) in this constellation. But because of a slow wobble in Earth's axis which changes all the celestial coordinates, the point of crossing, or the vernal equinox, has since slipped westward well into the adjoining constellation Pisces.

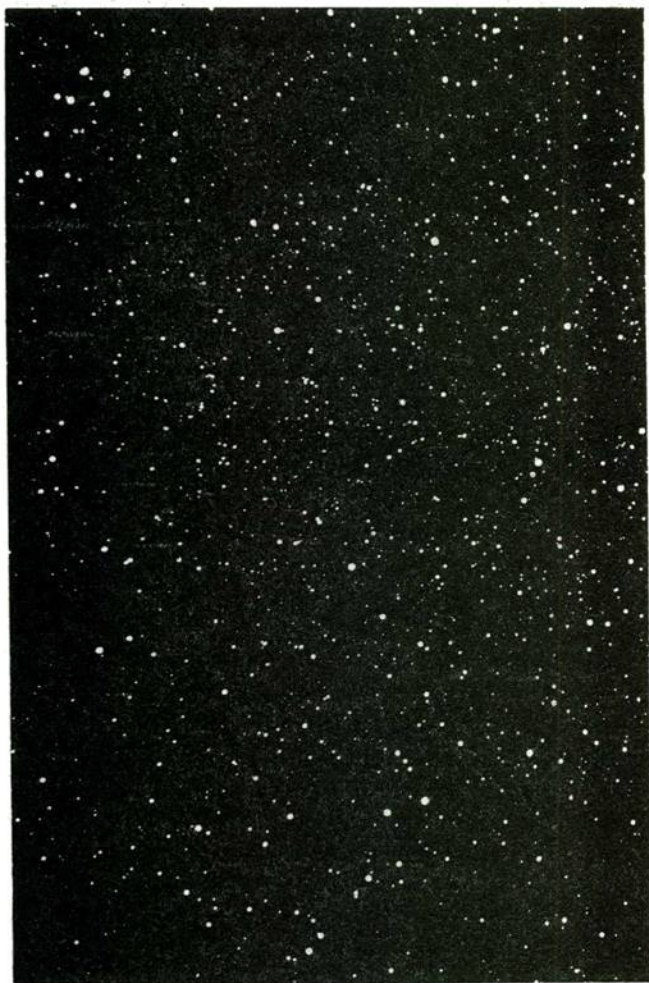
Aries has only two bright stars, Hamal and Sharatan. *Hamal* (ha-MAHL), meaning "the sheep", originally was the Arabic name for the whole constellation. It's a yellow star of 2.23 magnitude. *Sharatan* (SHARE-uh-tan), coming from the Arabic for "sign" or "mark", is magnitude 2.72. Its name strongly suggests that at one time it was at or near the point of the vernal equinox.

Between Aries and the Great Square of Pegasus lies the constellation **Pisces** the fishes, the first of several "watery" constellations in this area of the sky. Pisces (PYE-seez) is a long and large grouping containing no star brighter than about fourth magnitude.

Supposedly representing two fishes, you can trace it most easily if you start between Triangulum and Pegasus. Six stars here portray the northern fish. Follow the line of stars down and to the left for about 25 degrees, where you'll see 4.3 magnitude *Alrishah* (al-REESH-ah), the cord, symbolizing the line tying the tails of the two fish together. Next follow the line of stars to the west from *Alrishah* until you are below the square in Pegasus. Here you'll see a slightly bent circle of stars, all of fourth magnitude. This is the western fish. None too prominent, are they?

To the south of Aries and Pisces swims **Cetus**, the whale or sea monster. Belonging to both the Perseus legend and maritime group, Cetus (SEE-tus) was the monster sent to attack Andromeda. He has also been identified as the whale that swallowed Jonah. He's supposed to be swimming to the west, but antiquity, perhaps not having a clear idea of whales' anatomy, had him swimming to the east! As we see it, his flukes are up under Aries and can be seen as a roughly diamond shaped ring of stars. The outstanding star among them is named *Menkar* (MEN-kar), the nose — a red star of magnitude 2.54.

The body of the whale is below Pisces, and the constellation's brightest star is here. It's called *Deneb Kaitos* or sometimes *Diphda* (DIFF-dah) — the latter name is preferable to avoid confusion with the star in Cygnus. *Diphda* is yellow and shines at magnitude 2.02. In the tail between the body and



In the upper right is the flattened square of Delphinus, and to the south and east lies the little group of Equuleus. Still farther to the south is the westernmost of Aquarius' two water jars, and part of Capricornus. Deceivingly dim, the region abounds in objects for binocular "sweeps". Photograph by Brad Wallis and Robert Provin.

the flukes is a remarkable star, *Mira*. Taken from the Latin, its name means "the marvelous" — and it's certainly appropriate. *Mira* is a red star that changes its brightness from third to ninth magnitude over a period of about 330 days. Because the lower magnitude is below the limit for naked eye observation, in effect *Mira* turns on and off!

West of the body of Cetus is the zodiacal constellation **Aquarius** the water carrier. **Aquarius** (ah-KWAR-ee-yus) isn't a very distinctive constellation. To locate it, follow a line from Alpheratz to Markab in the Great Square, and extend it to the southwest a distance about equal to that separating them. This puts you close to *Alpha Aquarii* or *Sadal Melik* (sah-DAHL meh-LEEK), the lucky one of the king, which marks the center of the rod supporting the two water jars.

A little to the southwest is the brightest star in Aquarius: 3.07 magnitude *Sadal Suud* (suh-OOD), the luckiest of the lucky. While the constellation is best seen as two water jars carried on a pole, the resemblance is more to a bent pair of pince-nez spectacles! The right water jar lies west of *Sadal*

Suud, and is represented by a 10 degree oval of fourth magnitude stars.

Going back to the northeast past *Sadal Melik* and then down to the southeast brings you to the left water jar, comprised of about 10 stars 15 degrees in diameter. The eastern water jar has a pretty little grouping made from three stars at the 10 o'clock position. Binoculars will show this triplet of fourth and fifth magnitude stars very well.

Another little asterism is the bunch of four stars just to the left of *Sadal Melik* shaped like a lying down Y. The one nearest *Sadal Melik* is called *Sadal Achbia* (AKH-bee-yah), the lucky one of the tents. It's thought that the name is derived from the fact that this star rose near the sun in spring, when the rigors of winter were over and the nomads set up their tents in new pastures.

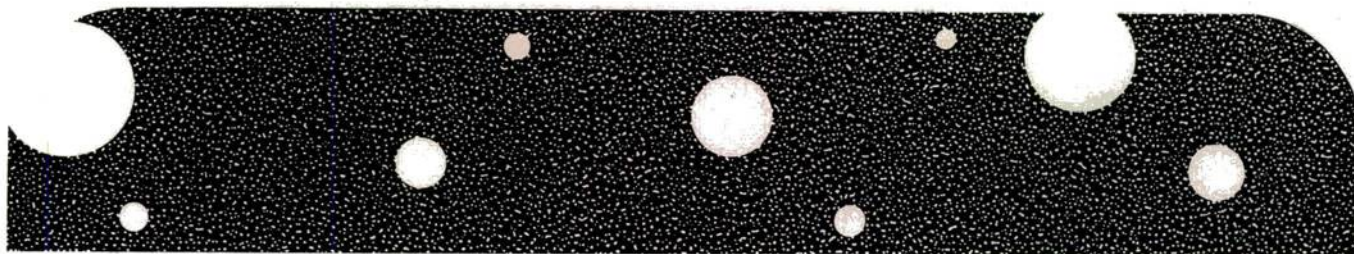
South of Aquarius and probably not very far above your horizon you'll notice a bright star. This is *Fomalhaut* (FOAM-al-hott), magnitude 1.3, in the constellation **Piscis Australis** (or **Austrinus**), the southern fish. The rest of the constellation — *Fomalhaut* is its mouth — spreads to the west in a triangular shape like a pennant. *Fomalhaut* is the most southerly first magnitude star you can see from midnorthern latitudes.

North and westward of **Piscis Australis** lies **Capricornus** the sea goat, another zodiacal group. The constellation looks much like a wide shield and has no truly bright stars. At the western point or tip of the shield is fourth magnitude *Giedi* (gye-EDDY) the goat. This star is a naked eye double, meaning that a close look at it will reveal two stars there. The components are magnitudes 3.77 and 4.55. Try your binoculars on them!

About two degrees south of *Giedi* is another double: *Dabih* (DABBY), meaning "the slaughter". You'll need binoculars to split this double, however. If you do, you'll see two stars — one at magnitude 3.3, and the other at 6.0. The eastern side of the shield is marked by *Deneb Algiedi*, the tail of the goat, at magnitude 3.0.

The last constellation we'll look at (and which finishes off the fall group) is sandwiched neatly between Pegasus and Delphinus, near Pegasus' nose. This is **Equuleus** the foal. **Equuleus** (eh-KWOOL-ee-yus) won't overwhelm you, but surprisingly has been in the sky since the time of Ptolemy — about the 2nd century A.D. It represents the foal's head with a trapezoid of five stars, all fourth magnitude or dimmer, and really is more a test of imagination and eyesight than anything else!

This installment is the last in our series on "Learning the Constellations" (see "Winter", December 1977; "Spring", April 1978, and "Summer", July 1978). We've shown you almost all the groupings visible from the northern temperate latitudes. If this is your first introduction to the sky, don't be concerned. Each part is self-contained. Now that you've finished, read the other three parts to familiarize yourself with the rest of the sky! 🐾



STELLAR FRONTIERS

Large Numbers, Cosmic Coincidences and Gravity

by
Jeanne Hopkins

Scientists like to play with numbers — the bigger, the better. Unlike mathematicians, however, physicists and astronomers demand that their large numbers have some physical meaning. The mathematician's googol, 10^{100} (a 1 followed by 100 zeros), has no physical reality; there is not a googol of anything in the entire universe.

With that *caveat*, then, what is the largest physical number there is? It would have to be something very large expressed in very small units, like the number of inches in a light-year (in round numbers, 10^{17}). But there are larger dimensions than light-years, and there are smaller units than inches. The largest possible length is the diameter of the universe itself. The smallest physical length is the diameter of an atomic nucleus. What is the ratio between them? The answer is 10^{40} . (Maybe it's only 10^{39} ; you can't be exact about such large numbers. Estimates could be as much as 10 times too large or too small! One of the rules of cosmic physics, according to Soviet theorist V. L. Ginzburg, is that if one large number is no more than 10 times another large number, the two are presumed equal.)

Instead of length, take time. The longest possible time is the age of the universe. The shortest

time that has physical meaning is the time it takes light to cross an atomic nucleus. What is the ratio between them? Answer: 10^{40} .

On reflection, it doesn't seem strange that these two ratios are the same. After all, the universe is expanding, so as it grows older, it gets larger. The two ratios are undoubtedly connected.

Let's take a third ratio. Earth and the other planets are held in orbit by the gravitational attraction between the sun and the planet. Likewise, electrons in an atom are held in orbit around the atomic nucleus by the electric attraction between the positively charged nucleus and the negatively charged electrons. But there is also a gravitational attraction — negligible though it ordinarily is — between the nucleus and the orbital electrons. What is the ratio of the electric attraction between an electron and a proton to the

Sprawled across light-years of space, the Great Nebula in Orion is still only a speck on the scale of the galaxy, and the galaxy only a speck in the whole universe. Between the scale of atoms and the scale of the universe, between the masses of single atomic particles and the mass of the entire universe, between the numerical ratios of some of the constants of nature, astronomer-cosmologists have suspected a link — a numerical coincidence too intriguing to ignore. Photograph copyright © 1978 by Cerro Tololo Interamerican Observatory. →





gravitational attraction between them? Answer: 10^{40} .

Now that *is* surprising! The electromagnetic and gravitational forces are traditionally considered to be constant — unchanged since the universe began.

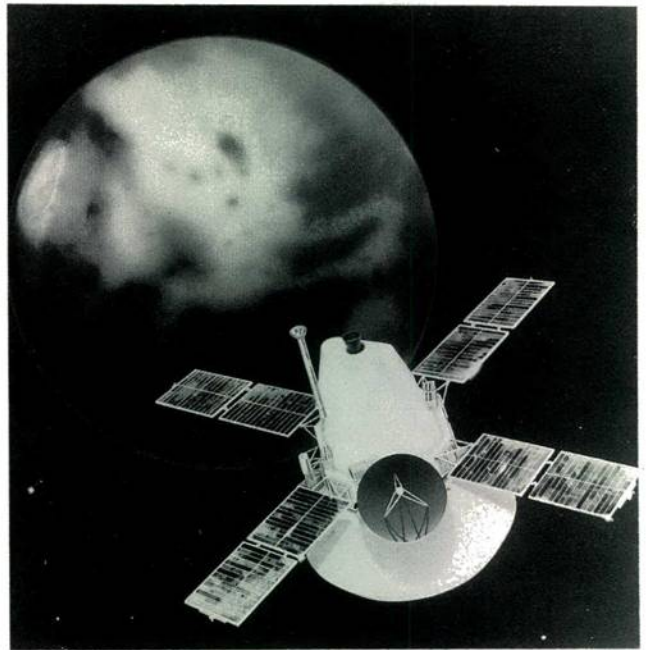
The search for large physical numbers is not new. More than 2,000 years ago, in a remarkable paper entitled “The Sand Reckoner”, Archimedes calculated the number of grains of sand it would take to fill the known universe out to the “fixed stars”. If Archimedes’ number is multiplied by the number of nucleons (neutrons and protons) in a grain of sand, the number comes out to about 10^{80} — the square of 10^{40} . Oddly, this is just what Eddington, 50 years ago, calculated for the total number of nucleons in the universe. (The total number of all particles in the universe — including massless particles like photons and neutrinos — is believed to be about 10^{88} — only a trillionth of a googol.)

What’s so special about 10^{40} ? Do we just happen to live in a “preferred” instant of time when all of these ratios are strikingly similar? Obviously, when the universe was younger and smaller, the first two ratios would have been smaller, but the third ratio would presumably remain unchanged.

Of course, we *do* live in a special time and place. Life could not have arisen until there were enough “heavy” atoms like carbon and oxygen to be incorporated into living cells, and these were not present until billions of years after the big bang. Nor could life — at least life as we know it — evolve on a planet where the mass, temperature, chemical composition, and many other requirements were not exactly right. The very fact that we are here implies that in our small corner of space and time — and so far as we know, *only* in our small corner — all of the improbable conditions necessary for the emergence of life were met. But by and large, physicists are skeptical of “coincidences”. They have learned to be equally skeptical of any theory that places man in a special position in space or time. Their theories generally reflect this bias against special conditions.

The Nobel prizewinning physicist P. A. M. Dirac was one of the first — in 1937 — to consider the large number ratios, and he has recently returned to studying the problem. Based on Einstein’s equations, he has constructed a new model of the universe which, appropriately enough, is called the *large numbers hypothesis*. Dirac concluded that the striking similarity between these large numbers cannot be a coincidence. It must be a result of the way the universe is set up — a property of the universe itself — and the similarity must always hold.

The first two ratios obviously increase with time. If the similarity between them and the third is always to hold, then the ratio between the electromagnetic and gravitational forces must also



Viking contributed to cosmology, as well as the study of Mars. Precise timings of its radio signals permitted physicists to test Einstein's theory of relativity with greatly improved sensitivity. The result: Einstein passed with flying colors! NASA artwork.

increase with time. In other words, either the electromagnetic force must increase or the gravitational force must decrease with time.

Dirac chose the latter alternative. (The late Russian-born American physicist George Gamow suggested that the electron charge, and therefore the electromagnetic force, might increase with time, but his suggestion was ruled out on experimental grounds. Within the past three years, observations of distant radio sources whose “light” was emitted billions of years ago have shown that the electromagnetic force has changed by less than two parts in a trillion per year in the billions of years since the radiation left those sources.)

More than three centuries ago Newton showed that the gravitational attraction between two bodies is directly proportional to the product of their masses, and inversely proportional to the square of the distance between them. To change the “proportional to” to “equal to”, a very small number G (Newton’s gravitational constant) must be inserted. Thus the ratio of gravitational force depends on a number of fundamental constants: Newton’s gravitational constant G , the mass of the electron, Planck’s constant, and the speed of light. The values of the last three quantities are known to extremely high accuracy, and recent efforts have been made to determine their values even more precisely. It’s clear that any variation in the last three constants is far less than the amount required by the large numbers hypothesis. If any quantity varies, it must be the gravitational “constant” G .

In the last few years other cosmological theories have appeared in which the value of G

decreases with time, so Dirac is no longer alone. Notable are the Brans-Dicke and Hoyle-Narlikar theories. Like Dirac's, both are modifications of Einstein's general theory of relativity. (In Einstein's theory, G is a true constant.)

In Dirac's theory, the value of G is inversely proportional to the age of the universe. With the presently accepted age of 18 to 20 billion years, Dirac's hypothesis corresponds to a decrease of about eight parts in 100 billion per year in the value of G . (The Brans-Dicke theory predicts an even smaller decrease — about six parts in a trillion; the prediction of the Hoyle-Narlikar theory is close to that of Dirac.)

We've known for at least a century that the moon is gradually receding from Earth, increasing its orbital period by about 1.6 thousandths second per century, because of tidal friction. The tides slow down the rotation of Earth, and the angular momentum thus "lost" by Earth is transferred to the moon's orbit. If gravity is growing weaker, then planetary and satellite orbits should adjust their sizes in response, and the moon's period should show an extremely small increase (a few millionths second) in addition to the amount due to tidal friction.

Only within the last decade has it become even theoretically possible to measure such a small change. Before atomic clocks were available, the fundamental unit of time was the ephemeris second. This is defined as a certain fraction of the tropical year — the period from one vernal equinox to the next. In practice, ephemeris time is determined from lunar observations. There would be no way of detecting a change in the value of G if ephemeris time were used, because the moon's period around Earth would change in the same proportion as Earth's period around the sun.

In 1967, however, the task of determining the exact value of the second was taken away from the astronomers and given to the physicists. The present unit of time is the atomic second which is based on a certain frequency of radiation emitted by a cesium atom — so it is presumably independent of the orbital period of Earth or the moon.

Thomas C. Van Flandern of the U. S. Naval Observatory has taken advantage of this new way of measuring the passage of time, to determine whether G is decreasing. He has studied plates taken of nearly 2,000 grazing lunar occultations over the past 20 years. In a grazing occultation, the star skims along the edge of the moon's disk, disappearing behind a lunar mountain and reappearing an instant later above a lunar plain. Such events can, in principle, be timed with great accuracy. If the radius of the moon's orbit around Earth is increasing because of a declining value in G , grazing occultations should occur (by atomic time) a small fraction of a second later than predicted.

Van Flandern has used both the ephemeris

second and the atomic second to time his occultations. Any discrepancy between the times measured by the two methods must, according to Van Flandern, be due to a changing value of G . He has interpreted his observations to show that G is decreasing by about nine parts in 100 billion per year.

If Van Flandern's interpretation is correct, it might help geologists explain some of the internal motions of Earth, such as plate tectonics and continental drift. As its self-gravitation weakened, Earth should slowly swell, by roughly the thickness of this page per year, gradually forcing the movement of its crustal plates. On the other hand, cooling and settling effects in Earth's core should cause its surface to shrink by roughly the same amount. Whether these two effects exactly cancel, or whether there is a small residual one way or another, is extremely difficult to determine, since Earth's surface is constantly being reshaped by various geological processes.

Another effect of a decrease in G would be a slowing down of Earth's rate of rotation (a lengthening of the day) over and above that due to tidal friction. Studies of growth marks on ancient coral laid down in the middle Devonian period (390 million years ago) show that the day then was slightly less than 22 hours long — just about what would be predicted from tidal friction alone.

Instead of trying to isolate the cumulative geological effects of a possible decrease in G over millions of years, astrophysicists have turned to the possibility of detecting celestial effects over minutes, seconds, or even less.

One of the early triumphs of Einstein's theory was its prediction of the 43 seconds of arc excess in the advance of Mercury's perihelion. According to Kepler's first law, a planet describes an ellipse around the sun, with the sun at one focus. Newton later showed that the other planets would have a gravitational effect on this ellipse: They would "perturb" the ellipse so that the planet's perihelion would occur slightly earlier than if no other planets were present. But even when all these perturbing effects were taken into account, astronomers noted that every century, Mercury's perihelion was advancing 43 seconds of arc more than could be explained by Newton's physics.

Einstein's theory accounts exactly for the 43 seconds of arc. The Brans-Dicke theory predicts only 39 seconds of arc excess, and Dicke maintains that the other four seconds of arc come from the solar oblateness, which was not taken into account by Einstein. It is well known that a rotating sphere of gas like the sun should show a slight bulge at the equator. This is hard to determine for the sun, because astronomers disagree as to just where the "edge" of the sun is, whether it bulges or not and, if it does, whether the gravitational bulge is enough to account for four seconds of arc of Mercury's perihelion advance.

Another of Einstein's predictions is that light is affected by gravity: Starlight that passes close to a massive body like the sun will be bent into a curved path by the sun's gravitational field, and the star will seem displaced in the sky. Einstein predicts that starlight just grazing the sun will be deflected by 1.75 seconds of arc; the variable G models predict a few percent less than this. This gravitational bending of light has been observed at every solar eclipse for the past 60 years. But because of the short time that an eclipse is total, the error in calibration of photographic plates, and the unrepeatability of the precise conditions, measurements taken during a solar eclipse are probably accurate to only about 80 percent — not enough to distinguish between the various models.

Radio astronomers do not have to wait for a total eclipse of the sun to take their measurements. Every October the sun passes very close to two quasars in Virgo; in fact, it actually occults one of them. Very long baseline radio observations of the quasars made in 1971 showed almost perfect agreement with the Brans-Dicke theory, although the uncertainty was enough to include Einstein also. The latest measurements of the same two quasars are within one percent of Einstein's prediction.

In 1964, Massachusetts Institute of Technology physicist Irwin Shapiro pointed out a corollary to the gravitational deflection of light: A light ray (or a radio or radar beam) that suffers this gravitational deflection should arrive at Earth slightly later than if it had traveled in a "straight" line. (The word "straight" is in quotes, since a straight line is often defined as the path of a light ray.) Under Einstein's theory, this time delay would be 200 millionths second for a beam that just grazes the sun; the other models predict slightly less than this.

For the past 10 years, Shapiro has been devising ever more accurate radio and radar techniques to test this time delay effect. The early radar observations of Shapiro and his colleagues were of an inner planet — Venus or Mercury — when it was on the opposite side of the sun from Earth. Those observations were limited primarily by our ignorance of the topography of the inner planets. In a millionth second, light travels almost 1/5 mile. If there is a five mile difference between the peaks and valleys on Venus, that means the round trip travel time of a radar signal bounced off a Venusian peak would be nearly 50 millionths second less than the comparable time for a signal bounced from the surrounding plain. (It is this principle that is used to map the cloud shrouded surface of Venus.) Those early measurements were not accurate enough to confirm or rule out all the competing models, although they showed slightly closer agreement with Einstein.

Shapiro's most recent experiments were made near the last conjunction of Mars in 1976 — timing

the 248.5 million mile round trip of a radio signal to the Viking orbiters and back. Those observations, which had an uncertainty of less than one percent, showed a delay of 200 millionths of a second — exactly the amount predicted by Einstein's theory.

All the measurements are extremely difficult. Because of the complex corrections and assumptions that must be made, they are prone to error. In fact, the amount of possible error usually exceeds the difference between the predictions made by the various models. One source of error is that, although the speed of light in a vacuum is known very accurately, interplanetary space is not a perfect vacuum. A large solar flare — injecting solar wind gas between the planets — occurring when a signal was propagating could have a tiny but significant effect on the signal. Even the passage of a warm or cold front through Earth's atmosphere could affect the time of the signal's arrival!

A more fundamental problem is that, according to Einstein and all the models based on Einstein, the rate at which a clock keeps time varies inversely with the strength of the gravitational field it is in. If gravity is weakening, then the rate at which any clock keeps time will speed up, and an observer located in the gravitational field will be unable to detect any change. Such an effect, however, would be extremely small. Furthermore — in principle, at least — scientists can calculate what it should be and correct for it.

Both Einstein and the decreasing G models have their advocates, and the different competing theories have aroused strong feelings comparable to the clash between the big bang and steady state theories a decade ago. Some scientists favor Einstein because his theory is the simplest and most elegant, because it doesn't contain "fudge factors" as the variable G models do, or for other philosophical reasons. Others lean toward one or another variable G model because it explains the large numbers ratios, because it is intellectually satisfying, or because it avoids the "singularities" and black holes implicit in Einstein's theory.

It's likely that the final word has not yet been said. The ideal model would be one which explains why these large numbers have the values they do, and which also explains other apparently arbitrary numbers such as 1836 for the ratio of the mass of a proton to that of an electron.

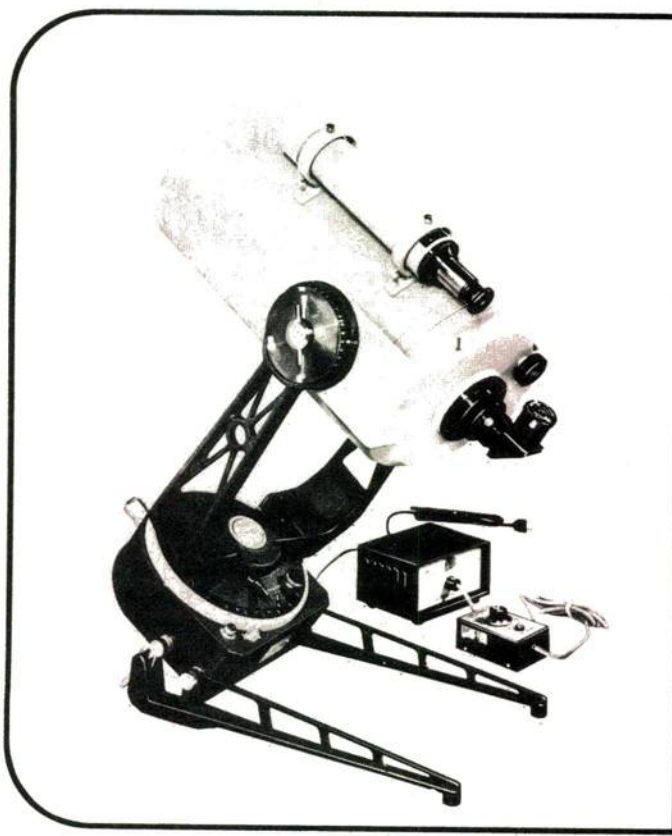
With attacks on the problem coming from all directions, the next few years may provide the answer. Is gravity weakening? Or do all the decreasing G models consist of nothing more than playing with numbers? 

Jeanne Hopkins has been chief manuscript editor for the Astrophysical Journal since 1967. Her work allows her to be unusually well informed about the current thinking in astronomy and cosmology. Hopkins' very useful book, A Glossary of Astronomy and Astrophysics, was published two years ago by the University of Chicago Press.

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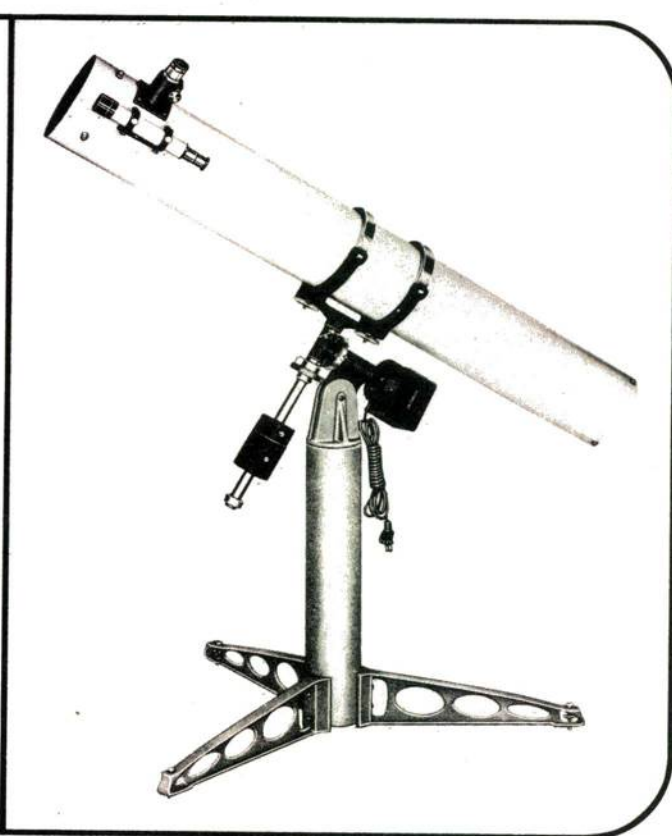
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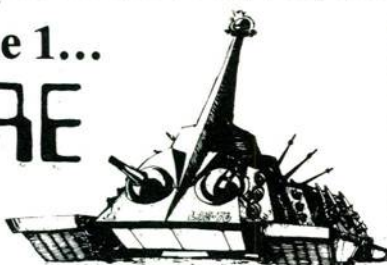
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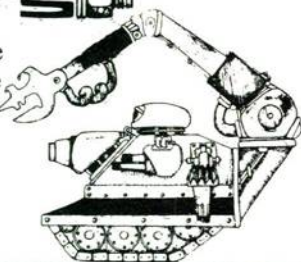
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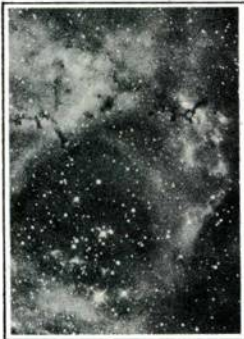
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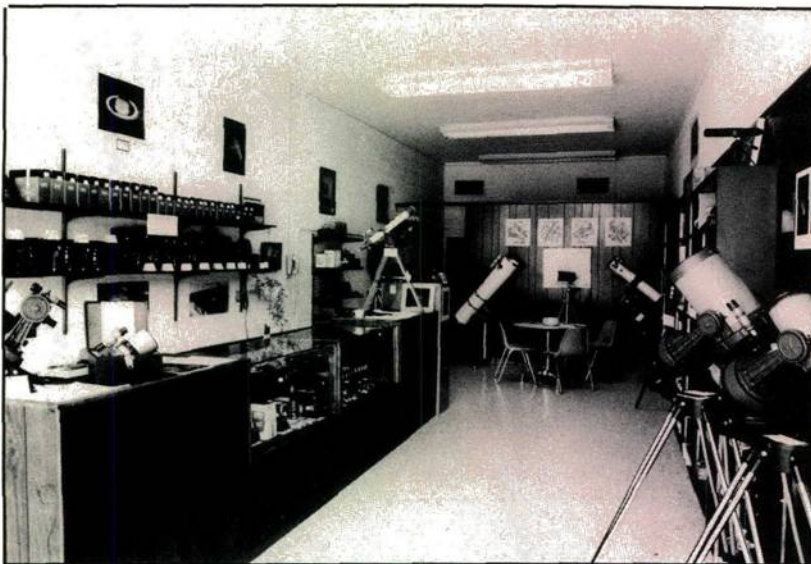
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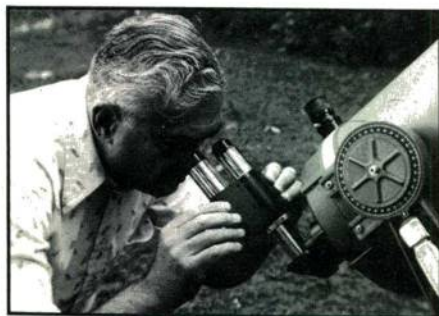
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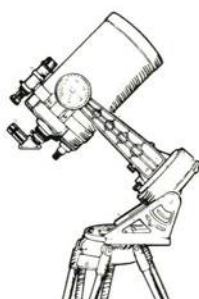
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TRADE — Complete set of ASTRONOMY (August 1973 to present); excellent condition. My interests: telephoto mirror-lenses (C-90, etc.); radio control gear/airplanes; electronics; music; optics; tools; photography; firearms. Write Skip Campisi, 1014 Knopf St., Manville, NJ 08835.

WANTED — ASTRONOMY back issues: September, October, November, December 1973; August 1974. Indicate price and condition. Write Bert Felter, 1603 W. White Oak Ave., Independence, MO 64050.

WANTED — Electric clock drive and camera adapter (non-SLR) for Mayflower #816 refractor (D-76mm, f-1,200mm). Also need erecting prism, eyepieces, miscellaneous parts. Contact Gary Fender, 9616 St. Andrews Dr., Santee, CA 92071. Phone (714) 449-1281.

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Send \$5.00 for copy of auction catalog, available September 1st. Include \$1.00 extra for later mailing of prices realized. Admission without catalog, \$2.00. Rules for mail or absentee bids and conditions of sale are specified in the auction catalog.

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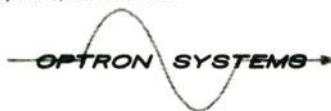
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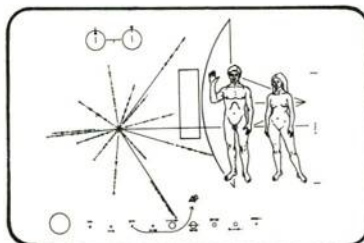
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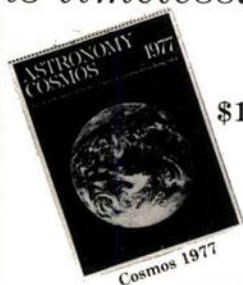
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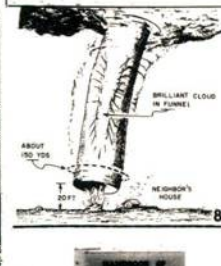
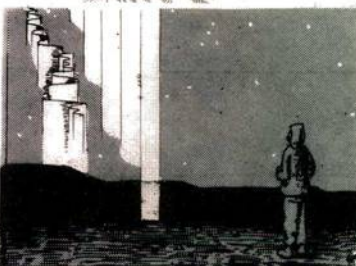
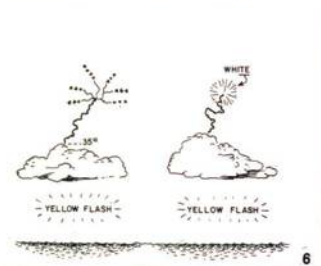
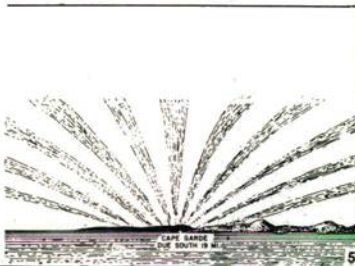
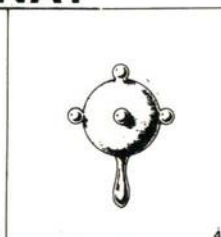
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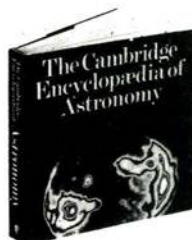
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OCTOBER

by

James Mullaney

This month we highlight another of the "watery" heavenly precincts — Aquarius the water carrier. Ranking 10th in size among the 88 recognized constellations, this dim figure occupies the sky between the Great Square of Pegasus and the bright blue-white star Fomalhaut in Piscis Austrinus, the southern fish. Look for it astride the southern meridian about 9:00 p.m. local time on mid-October evenings.

Barns introduced Aquarius as follows: "The water bearer, the 11th zodiacal sign, is a vast region with a few scattered objects of moment, and these are well worth consideration. Good prospecting to eastward." Webb found it "a dull looking constellation, but well repaying telescopic research", while Olcott noted that "for the possessors of small telescopes the constellation offers many interesting and beautiful objects". Before sampling this telescopic treasure in our Close-Up section, let's see what's of interest here for naked eye stargazers.

The most striking part of Aquarius is the neat asterism known as the water jar. This Y-shaped grouping consists of four nearly matched stars near fourth magnitude — a starry triangle formed by Gamma, Eta and Pi Aquarii, centered on the gem Zeta. The celestial equator (the extension of Earth's equator into the sky) passes through this grouping, just a few minutes of arc north of Zeta itself. Interestingly, rather than a jar here, the ancient Arabs pictured a tent pitched in a celestial desert!

In his account of this group, Olcott pointed out: "The four stars forming

the water jar make an attractive naked eye object. Sweep with an opera or field glass below the water jar down the sky in the direction of Fomalhaut where you will observe many pairs and triplets. The ancients thought that these stars represented water trickling down the sky ... into the gaping mouth of the southern fish." Since the earliest times, Aquarius has represented the figure of a man pouring water from an inverted jar or bowl. It's easy to see why, on a dark transparent night, the misty stellar sprinkling mentioned by Olcott does indeed look like water droplets, suspended in flight among the stars!

Other pairs and groups of stars can be found throughout Aquarius, including the duo formed by Tau-1 and Tau-2 Aquarii. Tau-1 is a 5.7 magnitude white sun and Tau-2 a 4.2 magnitude orange one, separated by slightly more than the moon's apparent size. Can you resolve this optical pair with the naked eye? Binoculars will be needed to appreciate their contrasting tints.

Another pair of stars to note are Alpha and Beta Aquarii. Although separated by more than 1/2 hour of right ascension and over five degrees declination, they have amazingly similar physical properties. Both shine at apparent visual magnitude 2.9; both are G type supergiant stars lying at nearly identical distances from us (just over 1,000 light-years), and both have the same radial velocity and proper motion! This strongly suggests they are somehow related to each other; yet at their great distance, they could

hardly form a double — even a wide, common proper motion one in the usual sense of the term. Could they be remnants of a long dissolved stellar association (see "Swarms of Stars: Cosmic Calibrators", March 1978)?

Alpha Aquarii carries the Arabian designation Sadal Melik meaning "the fortunate star of the king", while Beta is Sadal Suud or "the luckiest of the lucky". As Olcott pointed out, "The stars in this region appear to have been in great favor with the early astrologers, in spite of the fact that they appeared at the inclement season of the year."

Yet another important stellar landmark in Aquarius is fourth magnitude Iota. One degree north of Iota, Galle found the planet Neptune on Sept. 23, 1846. Neptune's position had previously been calculated (from its perturbations of Uranus) by Adams and independently by Le Verrier. This distant world had actually been seen several times before its discovery by telescopic observers. On those occasions, however, it was mistaken for a star! Neptune has completed 2/3 of its first circuit of the sun since its recognition and now lies in the constellation Ophiuchus.

Among the binocular targets of interest in Aquarius are the long period red variable star R Aquarii and the bright globular cluster M-2, detailed in the Close-Up below. The variable lies about one degree southeast of the pair of stars Omega-1 and Omega-2 Aquarii, and is easily picked up when near maximum light. (This month it is near minimum and

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month. The same constellations are visible one hour earlier during the latter half of the month. To use this constellation finder, hold it overhead so the compass points line up with North, South, East and West in your backyard or viewing area. For example, to find constellations in the southern part of the sky hold the chart in front of you so the South compass point faces the southern horizon. Repeat this procedure for East, West and North. Since only the brighter stars are represented in this map, you should be able to trace out the geometrical shapes of the constellations with ease. To find planets, asteroids, etc., visible among the current month's zodiacal constellations, refer to the planet finder on page 28





Map by Adolf Schaller

requires a telescope to be seen.) The cluster is about eight degrees due west of Alpha Aquarii and appears as a hazy star in 7 to 10 power binoculars. A third object is the large — but faint — planetary nebula NGC-7293, situated 1.5 degrees west of Upsilon Aquarii and also described in Close-Up. It is one of the very few members of its class within reach of such instruments.

In addition to all the foregoing, Aquarius also offers two major annual meteor showers — along with several lesser ones — to delight stargazers: The Eta Aquarids can be seen in early May, and the Delta Aquarids in late July. Both of these cosmic fireworks displays have single observer rates of 20 or so meteors per hour at peak activity. In addition, three minor showers radiate from this region during the first half of August, but they are easily missed because of their low hourly rates.

All in all, Aquarius has much to offer the observer without a telescope. However, its real wonders lie immersed in the darkness of an autumn night and require a telescope to be seen in their full glory.

Close-Up

Zeta (ζ) Aquarii

Centered within the starry framework of the water jar is one of the finest double stars in the entire "aquatic" region for smaller instruments. This is Zeta Aquarii, an intense matched pair of 4.4 and 4.6 magnitude suns currently 1.8 seconds apart at position angle 230 degrees. Discovered by Christian Mayer in 1777, this duo was apparently forgotten until "refound" by William Herschel during his great sweeps of the heavens a few years later.

In good seeing (when the image is steady), a three inch refractor will nicely divide Zeta at 150 power or more. However, at lower magnifications or on unsteady nights, the two star images may appear in contact or even blended into a single bloblike image. Most observers consider this pair an ideal test for such an aperture since the components are so nearly equal in brightness. Brown, for example, said: "This is a test star for a three inch refractor — if you can see it even as a notched double, you have a good telescope." The stars are easily split and a superb sight in medium sized scopes, as our drawing with an eight inch reflector at 200 power hints.

Zeta Aquarii is a slow moving binary system whose exact orbital period is still uncertain; values ranging from 400 to 1,600 years have been determined by various workers. Charles Worley of the U.S. Naval

Observatory considers 850 years the best fit of the available data, agreeing well with the 856 years given by Belgium astronomer Jean Meeus. Meeus called this object a "beautiful binary". His calculations indicate that the two stars were closest in their apparent orbit in 1977 — at just under 1.8 seconds — and that they will be widest, at 6.4 seconds, in the year 2265. The separation is now very gradually increasing, but will not exceed two seconds until the end of this century. The position angle is slowly decreasing, which means the components are turning clockwise on the sky.

Barns simply remarked that Zeta lies "in center of cross", while Webb saw it as "A very fine object, easy with very small aperture. In center of triangle of nearly equal, naked eye stars." This pair also appears on many old lists of the finest double stars including those by Colas, Flammarion and Chambers, and was a "runner up" for William Pickering's prestigious roster of the sky's 60 finest showpieces. These observations and lists were made at a time when Zeta's separation was much wider than at present — three seconds or more. It's still a stunning sight today, but isn't the easy object it once was in small scopes.

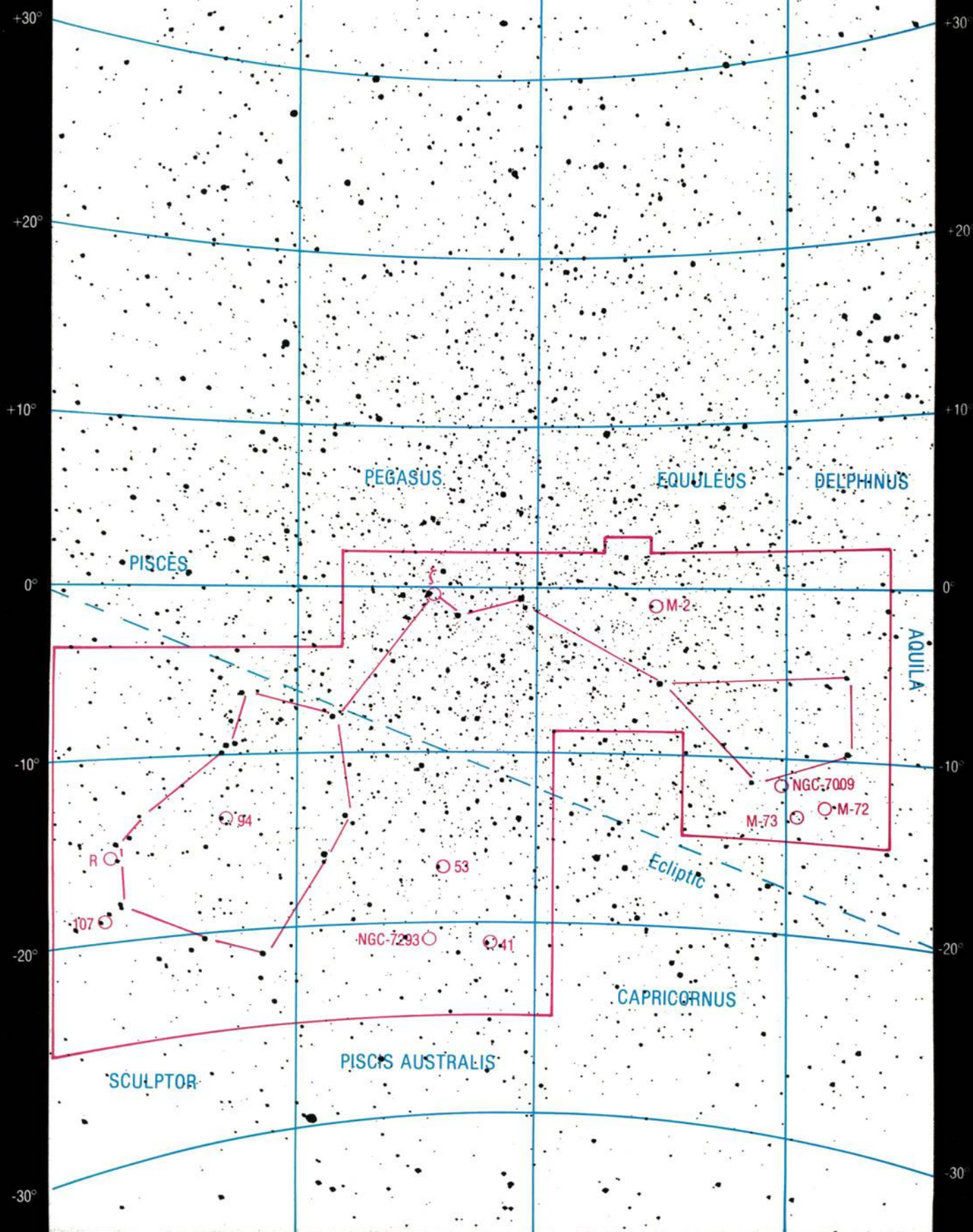
Admiral Smyth long ago called the components of Zeta Aquarii flushed white and creamy in tint as seen in his six inch refractor. Webb recorded them as both greenish white at one time and as pale yellow another. Most observers agree with Olcott that the stars are white, but others find subtle off-white hues present. Both suns are early F type stars which implies white is correct, but this is very close to the adjoining late A class which some astronomers consider green-white.

In addition to the two visible stars, there is also an unseen object circling one of them which is thought to be a faint dwarf sun. Thus Zeta is at least a triple star system — in this case lying about 75 light-years from our solar system. Seeing it will surely motivate you to further explore the hidden wonders of Aquarius!

94 Aquarii

If you prefer a little color in your doubles, take a look at our next offering. This is 94 Aquarii, a contrasting pair situated 4-1/2 degrees south of the Psi-1, Psi-2 and Psi-3 trio of naked eye stars. Here we find 5.3 and 7.5 magnitude suns an easy 13 seconds apart in a roughly north-south orientation on the sky. Like Zeta, this object is a long period binary and there is a third member of the system present.

Even a two inch scope at 30 power shows this pair nicely, but a four to six inch aperture is needed to really appreciate the colors present here. Barns tersely described 94 Aquarii as



"colorful", and Olcott said it displays "contrasting colors". Smyth logged the tints of the primary and its companion as pale rose and light emerald, respectively, and again as orange and flushed blue. Webb called this a "beautiful pair" and found the colors yellowish white and blue, and on another occasion "yellow with perhaps reddish glare, greenish". Still another impression is that of Brown who gave reddish white and light blue. And in a listing of the finest colored double stars by Colas from the 1890s, this duo is described as rose and light blue. What do you see through your telescope? For best results, use only highly corrected eyepieces and keep the object near the center of the field. Also try a slight defocusing of the image, which often helps color perception.

M-72

Some 3-1/2 degrees due south of Mu (μ) Aquarii lies one of Messier's globular clusters, but a rather poor specimen of its class. This is M-72, a two minute bundle of faint stars softly

glowing near ninth magnitude. You'll need a low power eyepiece on the telescope itself to sweep up this remote orb on a typical night.

An indication of its obscurity is the fact that M-72 was bypassed by most of the classic observers including Webb, Barns and Olcott. For an account we have to turn to contemporaries like Holyoke, who found this object "A rather small globular cluster with no unusual features. Easy to find but difficult to resolve. My six inch won't do it." The British observer Muirden pointed out that "the individual stars are so faint that a small instrument shows it simply as a circular nebulousity", and his countryman Kenneth Glyn Jones recorded it as

Left: The components of Zeta Aquarii are separated by a mere 1.8 seconds of arc, making them a challenge to small telescope users. In good seeing, however, a three inch refractor will split them. Right: NGC-7009, the Saturn nebula, doesn't resemble Saturn as much as it looks like a fantastic, eerie, blue-green cosmic egg. Drawings by James Mullaney.

"surprisingly difficult to resolve for so large and unconcentrated a cluster". Robert Burnham Jr. of the Lowell Observatory called it unimpressive except in large telescopes, and detected mottling around the edges with his 10 inch reflector at medium power using averted vision.

Your best view of this object will come when it is near the meridian (highest in the sky) on a night having both good seeing and transparency. Under such ideal conditions, does M-72 look like a sparkling globe or an unresolved nebulous blob in your scope?

M-73

An even more disappointing object than M-72 is its neighbor M-73. This is the famed "nonexistent" open cluster located 1-1/2 degrees due east and slightly south of the globular. This object is absent from the works of Webb and most of the other noted observers of the past, and apparently has never been seen by most of today's.

Holyoke said the following about M-73: "There is some doubt about including this object at all. It is called an open cluster but is actually only three or four stars, and is often considered nonexistent. You may be left in some doubt as to which three or four stars are included." Similarly, Burnham described this object as a "small triangle of three stars; not a true cluster" and again as "merely a knot of four small stars".

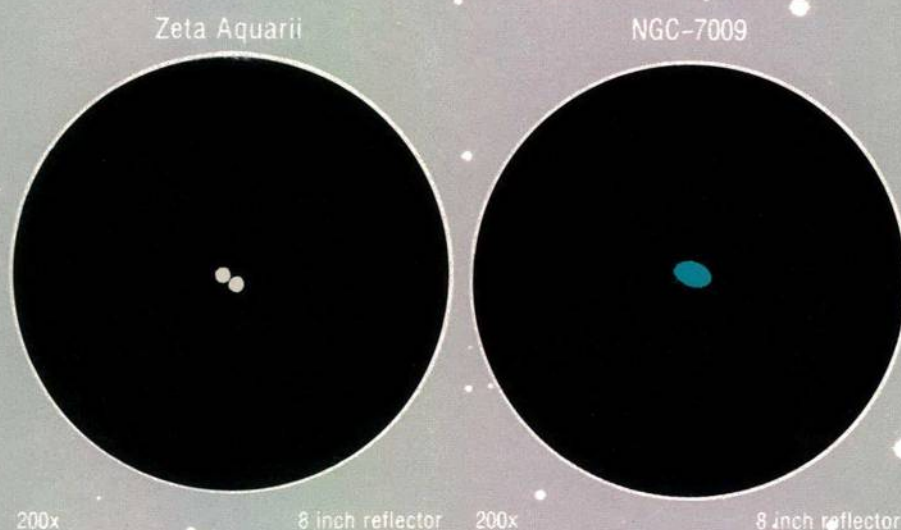
If you're puzzled as to why these observers can't settle on the exact number of stars in this little asterism, it's because they are rather faint, and their visibility depends on sky conditions and the size of telescope used. In a six inch reflector, for example, three stars are seen at low power, and four at medium to high power on a typical night.

Burnham gave the magnitudes of the individual stars making up M-73 as 10.5, 10.5, 11.0 and 12.0, and its size as only one minute of arc in extent. Messier thought it contained "a little nebulousity", but the **New General Catalogue** emphatically states "no nebulousity" is present. Small groups of faint stars often appear nebulous when near the resolution and magnitude thresholds of a telescope, and this is obviously the cause of Messier's remark here.

Although unimpressive at the eyepiece, it's still worth the time to locate and identify M-73 — if for no reason other than that offered by Smyth: "I give it out of respect to Messier's memory."

M-2

We are now about to make up for any possible disappointment caused by our last two subjects! To rekindle your enthusiasm for this month's region, take a look at the stunning globular



Selected Objects — Aquarius Region

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.
*M-72	GC	9.2	2'	20 ^h 51 ^m	-12°44'
*M-73	AS	10	1'	20 ^h 56 ^m	-12°50'
*NGC-7009	PN	8.4	44"x26"	21 ^h 01 ^m	-11°34'
*M-2	GC	6.3	8'	21 ^h 31 ^m	-01°03'
41	*2	5.7,7.2	5"	22 ^h 12 ^m	-21°19'
53	*2	5.7,6.4	6"	22 ^h 24 ^m	-17°00'
*ζ (Zeta)	*2	4.4,4.6	1.8"	22 ^h 26 ^m	-00°17'
*NGC-7293	PN	6.5	15'x12'	22 ^h 27 ^m	-21°06'
*94	*2	5.3,7.5	13"	23 ^h 16 ^m	-13°44'
R	RV	5.8-11.5	387 ^d	23 ^h 41 ^m	-15°34'
107	*2	5.7,7.0	6"	23 ^h 43 ^m	-18°57'

*Detailed in Close-Up

GC = Globular Cluster
PN = Planetary Nebula
*2 = Double Star
AS = Asterism

RV = Red Variable Star
Mag. = Magnitude
Sep. = Separation
Per. = Period

cluster M-2. It's easy to pick up in finders and binoculars on a dark night: Sweep for it about 1/3 the way from Beta (β) Aquarii to Epsilon (ϵ) Pegasi. It's also eight degrees due west of Alpha (α) Aquarii, appearing like a hazy star.

M-2 glows intensely near sixth magnitude, measures some eight minutes in diameter, and is considered rather highly concentrated as globulars go. It closely resembles M-15, which lies 13 degrees due north of it in Pegasus. An intercomparison of the two objects in your telescope should prove fascinating! This densely packed swarm is a fuzzy sphere in three and four inch instruments at low power, but at 100 diameters or more begins to glitter on a good night.

Webb described M-2 as: "Beautiful large round nebula, diameter five or six minutes, showing with 3.7 inch (refractor) a granulated aspect, the precursor of resolution. With nine inch speculum (reflector) resolution evident, the margin seems to diffuse itself away, probably in rays." Smyth, in his six inch refractor, noted: "This magnificent ball of stars condenses to the center and presents so fine a spherical form, that imagination cannot but picture the inconceivable brilliance of their visible heavens to its animated myriads." John Herschel compared this cluster to a "heap of fine sand" as seen in his large metal mirrored reflectors.

Bernhard, Bennett and Rice — like most observers, both past and present — were also excited about M-2: "Its magnificent stellar components resolvable in a nine inch or larger instrument and offering a superb view." In his 10 inch reflector, Barns saw here "thousands of suns compressed into a glowing opalescent mass". And finally, Burnham remarked that this object resembles "a little ball of glowing mist" in a two inch telescope, and that partial resolution can be achieved with a good 8 or 10 inch scope.

Amid all the excitement, mystery lurks in the observational literature. For some unaccountable reason, Pickering rejected M-2 from inclusion in his listing of celestial showpieces — despite the fact that he was using an 11 inch refractor from the superb skies of Jamaica! Even stranger, Olcott referred to this cluster as "a beautiful planetary nebula ... a fine sight in a three inch telescope".

This stellar beehive graces our autumn sky from a distance of nearly 50,000 light-years, silently awaiting your contemplative scrutiny.

NGC-7009

Next we examine two real but quite dissimilar planetary nebulae. One of these is NGC-7009, better known as the Saturn nebula. Sweep for its distinctive blue-green disk with a

medium power eyepiece 1-1/2 degrees due west of Nu (ν) Aquarii.

NGC-7009 measures 44 by 26 seconds of arc in apparent size, although visually it looks somewhat smaller. It shines near eighth magnitude and has a 12th magnitude central star that can be glimpsed in larger instruments. In a three inch refractor at 45 power, the nebula looks nonstellar — both in size and color. As magnification and aperture increase, it becomes ever more spectacular, appearing in medium sized telescopes like some eerie blue-green cosmic egg! Our drawing through an eight inch reflector at 200 power gives some idea of what to expect, but seeing it with your own eyes will make it come alive.

A careful observer using a 10 inch or larger scope can catch a glimpse of the thin rays or "ansae" that extend away from the disk's long axis on either side, giving rise to the name Saturn nebula (so dubbed by the imaginative Lord Rosse, who named many of the other bright nebulae). These faint extensions are well shown in observatory photos, as is a feeble halo surrounding the bright disk itself.

NGC-7009 is also designated HIV-1 (or 1^a in some atlases), being the first of William Herschel's discoveries in his class IV, planetary nebulae. Dreyer, who compiled the much used NGC, called this object "magnificent". Chambers reported: "Small, bright planetary nebula, stellar nucleus, blue color. Similar to NGC-6543 in Draco."

As usual, the most detailed of the classic accounts of NGC-7009 is that left by Webb: "Planetary; somewhat elliptic; very bright for an object of this nature; pale blue; not well-defined in 5-1/2 foot achromat (his 3.7 inch refractor), but bearing magnifying more like a planet than a common nebula. One of the finest specimens of these extraordinary bodies, to which their discoverer William Herschel assigned a distinct class. Earl of Rosse finds a very thin ray on each side, which I saw with Huggins' 15 inch achromat. Lassell detects within it a bright well-defined elliptic ring. Buffham, nine inch speculum, an opening. Secchi, who made its diameters 25 and 17 seconds, saw it sparkle, and thought it a heap of stars."

Among the modern impressions of NGC-7009 are those given by Muirden who found it a "bright elliptical...bluish, rather ill-defined", and Burnham: "The nebula is a strikingly beautiful object in large telescopes, shining with a vivid green fluorescent glow." Charming and informative as these descriptions from other observers may be, they are but the secondhand narratives of celestial travelers! To experience the thrill that is stargazing, you yourself must embark on a journey of nightly exploration into vast and beautiful realms — seeing with

your own eyes such wonders as these.

As in the case of M-2, we find mystery regarding NGC-7009. Pickering again rejected this showpiece from his roster even though it is an incredible sight in an instrument of the size he was using. And this time, it was Barns instead of Olcott who slipped in his account of this object: "Prodigious! Elliptical, pale blue and said to resemble the planet Venus."

Despite modern astronomical research, the distances of most planetary nebulae are only roughly known. The Saturn nebula appears to lie between 3,000 and 4,000 light-years from us — nearly 10 times that of our next and final offering.

NGC-7293

Generally considered the largest, brightest (in total light) and nearest of all the planetaries is NGC-7293. Better known as the Helix nebula, this giant celestial smoke ring is located 21 degrees directly south of Zeta Aquarii, and 1-1/2 degrees due west of Upsilon (υ). Distances as near as 85 light-years have been determined for this object, but a more likely value is around 500.

NGC-7293 has the integrated (or combined) light of a 6.5 magnitude star, but is so large in apparent size (15 by 12 minutes, or roughly half the apparent size of the full moon in the sky) that it has an extremely low surface brightness. As a result, it is easier to see in binoculars than in a large telescope — in much the same way that some of the extended diffuse nebulae we've encountered in the past are.

A four to six inch richest field telescope at 15 to 30 power is perhaps the ideal equipment with which to glimpse the Helix. The ring aspect so evident on photos is not easy to make out at the telescope. Most observers see a ghostly uniform glow at its position, and some feel it looks even larger than the above figures indicate. A dark (moonless) transparent night is essential for detecting it.

NGC-7293 was apparently unknown to the Herschels, Webb and other early observers, having been discovered by Harding in the late 1800s. Burnham said: "Binoculars will show the object as a large circular hazy spot, and it is not a difficult object for a small scope if a low power ocular is used...." It is a fascinating sight in 8 to 12 inch telescopes, providing a low power and wide enough field (at least one degree) are used.

After a pleasant evening spent exploring the sights of the Aquarius region under a clear autumn sky, you may find yourself in accord with the poet Van Dyke, who urged us all "To be glad of life, because it gives a chance to love and work and play, and to look up at the stars."

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